VOLUME 55
NUMBER 1

WHOLE NO. 249
1943

Psychological Monographs

JOHN F. DASHIELL, *Editor*

Studies of Ocular Behavior in Music Reading

Edited by

H. E. WEAVER
Oberlin College

I. A SURVEY OF VISUAL PROCESSES IN READING DIFFERENTLY CONSTRUCTED MUSICAL SELECTIONS

By

H. E. WEAVER

II. MEMORY SPAN AND VISUAL PAUSES IN READING RHYTHMS AND MELODIES

By

KELVIN VAN NUYS AND H. E. WEAVER

Published by

THE AMERICAN PSYCHOLOGICAL ASSOCIATION, INC.

Publications Office

NORTHWESTERN UNIVERSITY, EVANSTON, ILLINOIS

Science Lib.
Psychology
Direct
12-7-50
72597
V. 55, no. 1-5

TABLE OF CONTENTS

I. A Survey of Visual Processes in Reading Differently Constructed Musical Selections

H. E. Weaver

	Page
Introduction	1
Survey of Problem	2
Eye movements and the perceptual span	2
Music reading a many-sided process	3
Tempo and rhythm	4
The double staff	4
Sequential placement of pauses for different types of music	5
Eye-hand span	6
Comprehension and performance in music reading	7
Experimental Analysis	8
Results	12
Number of reading pauses	12
Duration of reading pauses	14
Tempo and ocular behavior	15
Frequency of errors	15
Individual differences	16
Sequential placement of pauses	17
Eye-hand span	23
Discussion of results	25
Summary	27
Bibliography	29

II. Memory Span and Visual Pauses in Reading Rhythms and Melodies

Kelvin Van Nuys and H. E. Weaver

Page

Introduction 33

The Problem 33

The Reading Material 34

Apparatus and Procedure 35

The Subjects 41

Results 41

Notes correctly executed 41

Notes explored visually 42

Regressions and rereading 42

Pause durations 43

Notes per pause 44

Effects of removing maximum span requirement 45

Discussion of results 46

Summary 48

Bibliography 50

STUDIES OF OCULAR BEHAVIOR IN MUSIC READING

I. A Survey of Visual Processes in Reading Differently Constructed Musical Selections[1]

H. E. WEAVER
Department of Psychology, Oberlin College

INTRODUCTION

Many different authors have published discussions of the general nature of music reading and the problems involved in the development of skillful sight reading. Some writers have presented methods which they believe should be used in developing the most efficient reading habits (7, 25, 41), and others have presented more or less detailed analyses of the reading process as it seems to them to be constituted (13, 22, 33). Where authors have attempted to analyze music reading as a psychological process, the influence upon their writing of general psychological theories (12, 14), of the popular physiology of the nervous system and receptors (12, 14), or of experimental studies of other kinds of reading (15, 26, 35), is clearly apparent. Such applications of general principles are often useful. However, music reading is an exceedingly complex process; it is in many respects different from other skills; and many phases of the performance cannot be studied adequately by means of unaided observation. Experimental techniques which may be used in studying some of the details of the process are available but little experimental research has been reported in this field.

The photographic method of recording ocular behavior has been used successfully in many studies of different kinds of reading. The belief that this method should prove very useful in analyzing music reading experimentally led to efforts to adapt the method to the special conditions involved in the reading of music. The experimental application of the method has been limited to the study of sight reading of piano music.

The study has been divided into two parts. The first part is a survey of the general aspects of the problem from the standpoint of the visual perceiving functions involved. This is based upon a consideration of the available evidence from studies of reading which seems relevant to a study of music reading, the nature of musical notion and the various components of a musical composition which must be read, the similarities and differences between music reading and other kinds of reading, etc. The second part presents the method used and the results obtained in a preliminary experimental analysis of some aspects of music reading by means of the photographic eye-movement technique. While musicians were reading different musical selections, records of the activities of their eyes and hands were made by means of which the number and durations of reading pauses, the sequential placement of pauses, the eye-hand span, and the accuracy of the manual performance could be determined.

[1] This paper is a revision of one part of a doctor's dissertation submitted to the Department of Psychology and the Committee on Graduate Study of Stanford University. Supervision of the study by Professor Walter R. Miles is acknowledged with gratitude.

SURVEY OF PROBLEM

Eye Movements and the Perceptual Span

General principles of visual perceiving which have been established by extensive research may be assumed to be applicable to music reading. Of these principles, those pertaining to the movements of the eyes in perceiving printed symbols and to the extent of the perceptual span are especially significant.

In all reading, the eyes move by a succession of rapid jerks during which there is no clear vision. The apprehension of the material to be read occurs only during the pauses between jerks. In the reading of words, the pauses constitute about 94 per cent of the reading time (36). The shortest pauses found in the reading of words usually have a duration of about .10 sec. (pauses of .06 to .08 sec. sometimes occur). Pause durations of 4 sec. and longer have been reported by Buswell in a study of eye movements in adding numbers (4).

We may assume that, in music reading, the eyes move by very quick jerks between reading pauses of variable durations. The movements should occur in such a manner as to make possible a coherent manual performance.

Experimental studies in which the tachistoscopic technique has been used have shown that a reader apprehends only a small number of symbols at each reading pause of the eyes. Tinker (37) has summarized a large number of tachistoscopic studies of visual apprehension. Results reported in these studies differ along with differences in the details of the experimental techniques used and methods of scoring. For the different investigators, the number of unrelated letters reproduced after one visual fixation varies between 3 and 7. Tinker cites studies which show that more letters are reproduced when they are presented in the form of nonsense syllables than when presented in unrelated series and that approximately as many unrelated words as unrelated letters are reproduced. He says, "A survey of these studies on visual apprehension indicates clearly that there is a natural tendency to combine the different elements of a visual impression into higher perceptual units whenever grouping is possible" (37, p. 227). The visual span in reading music must be similarly limited and a grouping into "higher perceptual units" may be expected in the reading of chords and frequently used melodic sequences.

In an experimental study reported by Ortmann (28), the size of the area within which notes can be perceived clearly enough to be reproduced after one reading pause of the eyes was determined. Also, the effects of different arrangements of notes upon the size of the area were studied. Using cards containing note groups on a five-line staff printed in the normal size (vertical distance approximately ¼ inch), he found that the visual field embraces a circular area varying between ¼ and ⅓ inch in diameter. Concerning factors involved in the arrangements of the notes he says, "The chief determinants of the difficulty in note reading which does not involve actual eye movements are the number of notes in the field, the area covered by the distribution of the notes, the number of linear dimensions involved, the complexity or symmetry of the note pattern, and finally the meaning of the note group from either a harmonic or melodic standpoint—or both" (28, p. 93). Ortmann's results show that the visual span in note reading is similar in size to the span in word reading and that "grouping" is a factor in note reading as well as in word reading.

Different kinds of note patterns were presented tachistoscopically to profes-

sional and non-professional musicians by Bean (1). The notes grasped by the subjects were reproduced by them at the keyboard. Professional musicians reproduced correctly after one visual fixation, one to nine notes. The average number of notes accurately reproduced when the music had a melodic organization was 4.72; when the notes had a polyphonic arrangement, it was 4.9; and when chords were used, it was 3.59. Non-professional musicians reproduced one to seven notes. The averages for melodic, polyphonic and chord arrangements were all lower than those for professional musicians (2.73, 2.15, and 3.06 respectively).

With an average visual grasp of only 3 to 5 notes per reading pause, it is apparent that the music reader must achieve a coherent and unified execution of a composition from a visually discrete succession of relatively small groups of notes.

Music Reading a Many-sided Process

In reading a piano composition, it is necessary to identify the pitch of a tone and its interval relations to other tones within a melodic sequence; the relative time value of each tone must be grasped along with its position within the rhythmic sequence; the relative intensity of each tone must be determined as a part of both the melodic and rhythmic patterns; groups of notes must be recognized as chords progressing within an harmonic sequence; the melodic, rhythmic, dynamic, and harmonic units should be read as parts of systematically organized phrases; and, throughout the phrase or many phrases, the reader must maintain a perceptual orientation to the tonality or succession of related tonalities employed. It is possible that a reader may be more or less skillful in carrying on any one of these phases of the reading process however complexly fused they may be in the case of the trained musician. And, although these different aspects of a composition are not independent variables within one selection, they may vary in prominence or complexity in different compositions. This means, of course, that they do not lie beyond the range of controlled experimental study.

In addition to the features of music just outlined, the reader must be able to translate into appropriate action a very large number of special signs which are necessary parts of the notational system. "Accidentals" may alter the pitch of a tone; time values of tones may be varied by means of the "tie," the "dot," and the "fermata"; time values may be changed, also, by the signs which indicate a change of tempo, such as "ritardando" and "accelerando"; variations in dynamics accompanying the normal rhythmic accents are indicated by many different signs such as "p," "sfz," "cresc." and "decresc."; a wavy line placed vertically beside a chord shows that the tones of the chord are to be played as a rapid arpeggio rather than simultaneously; the trill, the mordent, and the turn add embellishing tone groups to the tones represented by means of notes; legato and staccato playing are indicated by the slur and by dots above the notes; the fingering is given in many compositions and often the use of the pedal is indicated. These are only some of the more commonly used signs.

All of these symbols and their polyphasic organization must be clearly perceived by the reader in preparation for an exact manual execution of the symbolized forms. The necessity of producing an exact tonal embodiment of the printed symbols demands a perceptual process which seems to approach the highest degree of complexity, speed, and precision possible in human skills.

Tempo and Rhythm

The rhythmical character of music along with the requirement of a uniform tempo make music reading very significantly different from the reading of words. It is true, in the oral reading of words, that the accentuation of words and syllables involves the use of rhythmic groups. But these rhythmic groups are not organized about a regularly recurring measure beat or "takt" as is the case with music. It is the regular measure accent of a musical rhythm which distinguishes it from the rhythm of prose or poetry. The tempo of execution must always be considered in relation to any experimental measurements of the number or durations of reading pauses.

Of two readers of words, who read with equal comprehension, the one who reads most rapidly, i.e., with the smallest number and duration of fixations, is the more efficient reader. Tempo limitations restrict the application of this principle to music reading. The difficulty in applying the principle to music reading may be illustrated by statements from a study of eye movements in music reading by Jacobsen (17, 18). After presenting data showing the number and durations of fixations recorded photographically while pianists were reading music at an organ, one of his conclusions is that "In reading music the mature reader has few fixation pauses and these pauses are of average duration or less," and "The immature reader has many fixation pauses in reading music, and these pauses are of long duration." One is convinced by general observation that beginners read more slowly and, therefore, make more and longer pauses than well trained musicians. But Jacobsen says, also, that "It is certain that most of the subjects could have played the selections in less time than is recorded, and also have had an average duration of fixations of shorter length." This means that the relation between the tempi selected by his subjects and their maximum speeds of reading is unknown. When this is true, it is necessary to recognize the possibility that a more mature reader may read a selection at a slower tempo than a less mature reader because of a better realization that a hymn should not be played at a jig tempo.

More fixations of the eyes are made in oral than in silent reading of words (32, 16, p. 101). The speaking of the words retards the reading process and allows the reader to scan the page more thoroughly than is necessary for adequate comprehension. Undoubtedly a slow tempo in music reading would have a similar effect. Also, we may assume that all parts of a musical selection are not equally difficult to read. With a uniform tempo, it is to be expected that superfluous pauses will occur when the easier parts are read although the tempo may not permit them when the more difficult parts are read. The problem is further complicated by the fact that the appropriate tempo for a musical selection may be much slower than the maximum tempo at which the reader is able to read it and the playing of a composition at an unconventional tempo is a violation of a cherished principle for many musicians. A definite tempo is specified for nearly all compositions and it seems probable that the degree of difficulty of a composition which is read at its prescribed tempo is a more adequate criterion of maturity or degree of skill than the tempo or speed that is adopted by the subject when the prescribed tempo is not required.

The Double Staff

In reading piano music, two lines of

symbols must be read simultaneously. The treble and bass halves of the great staff are sufficiently far apart to require vertical movements of the eyes in reading them (34). This not only makes the pattern of eye movements in music reading more complex than in word reading but also makes necessary more elaborate recording apparatus.

Several methods have been used in recording both vertical and horizontal movements of the eyes. Judd and others (20) have used a kinetoscopic method. The Dodge method (38, 16, pp. 83-90) has been used with a lens for each eye and two films running at right angles. B. Clark (6) has used an inverting prism. Brandt (2) reports the use of two lenses with only one film which is carried over rollers so that it passes through the focal plane of the camera in both the vertical and horizontal directions. The "split beam method" used in this study and described below has been used by Jasper and Walker (19).

Many musicians have definite ideas concerning the advisability of reading the treble or bass halves of a composition first. The reading of chords from the bass upwards is often recommended. Ortmann (27) reports that, according to the introspections of his subjects, they read chords from the bottom up except for close groupings, in which the direction of reading was not noticed. Jacobsen (17) found that his good readers, with few exceptions, read chords from the top down. Poor readers read from note to note and from the two directions with about equal frequency. There are so many conditions that may play a part in determining the order in which reading pauses occur that it seems improbable that reading in one direction only would be most efficient for all kinds of music.

Sequential Placement of Pauses for Different Types of Music

Since the reader has to read two lines of symbols which may be significantly grouped vertically and horizontally; since rhythmic, melodic, and harmonic sequences should be read as coherent patterns; and since compositions differ greatly in the arrangement of notes on the page; the reader has a considerable task in visually assembling the different components in preparation for a unified manual performance. It seems apparent that the order in which the small segments of material grasped at each reading pause are pieced together may be either favorable or unfavorable for a quick apprehension of the musical whole.

Consideration of the organization of eye movements has not been neglected by investigators of other types of reading. Dearborn (8) has pointed out that his subjects apparently formed "short-lived motor habits" of eye movements. His subjects read successive lines of words with the same number of reading pauses. Other investigators have reported similar results and several men have emphasized the importance of regularity of eye movements during reading. Regressive eye movements which occur when the reader progresses from the end of one line to the beginning of the next represent complications in the organization of the ocular pattern of movements. However, the organization of movements or the sequential placement of reading pauses appears to be a much more important aspect of music reading than it is of word reading.

Considering the large differences in the organization of musical compositions, it would appear that corresponding differences should be found in the most efficient patterns or sequences of reading pauses for different types of compositions. Although it is practically impos-

sible to classify many musical compositions according to a particular type of organization, several general types of organization may be distinguished and used in classifying much of the available music. Music which is harmonic in organization may be distinguished from music which is melodic in organization. Of course, any melody has a harmonic structure and any sequence of chords will involve pitch changes which are characteristic of melodic progressions, but contrapuntal material in which each voice part retains its own rhythmic and melodic individuality within the complex of tones is primarily melodic in organization and sequences of chords in which the rhythmic pattern is practically the same for all parts are primarily harmonic in organization. Compositions in which a melody is accompanied by chords which supply a harmonic background constitute a third common type of organization. An immense number of varieties and combinations of these common forms may be found. No attempt is made here to give a type classification for all musical compositions. The types mentioned may serve as illustrations of organizational differences among compositions which appear to be significant in relation to the functions of the eyes in reading.

Eye-Hand Span

The eye-hand span in music reading corresponds to the eye-voice span in the reading of words. Quantz (30) seems to have been the first to attempt to measure the distance between the word fixated by the eye and word spoken by the voice in oral reading. He measured this distance by determining the number of words that could be read after a card had been unexpectedly slipped over the material being read. He reports that the span is greater at the beginning of a line than at the end and that special conditions, such as an unfamiliar word, may reduce the span to zero. Gray (16) used a similar method but obtained a record of the reading by means of a dictaphone. Buswell (3) used a dictaphone and made photographic records of eye movements. His recording mechanisms were synchronized so that corresponding points on the two different records could be determined. He used school children as subjects and reports that "for all grades the good readers have a much wider span than the poor readers, . . ." Also, "One of the characteristic features of the eye-voice span is its variation in width from word to word through the selection. The span is sometimes very wide and sometimes narrow, apparently expanding and contracting to the demands made by the material read." Butsch (5) used the photographic method in a study of the eye-hand span in typewriting. He found that his subjects were usually looking at the next word ahead of the one they were writing. His most rapid writers did not read two words ahead more than half of the time. He found a few three word phrases that were read ahead of the writing. Fairbanks (11) has reported results of a study of the relation between eye-movements and voice in the oral reading of good and poor silent readers which are very similar to those obtained by Buswell.

There is general agreement among music teachers that the eyes should be well ahead of the hands in reading but there is a great difference of opinion concerning the distance that a reader can or should maintain between the eye and hand. Published estimates and recommendations range from one or two measures to a whole page (25). This may indicate that individuals differ greatly in eye-hand span or it may be evidence that

unaided observation is not adequate to achieve reliable estimates.

Comprehension and Performance in Music Reading

Some of the difficulties in measuring comprehension in word reading have been discussed by Tinker (39). However great the difficulties, it seems evident that the significance of eye movement records of reading is severely limited if no evidence of the degree of comprehension of the reader is obtained.

To the extent that comprehension is expressed in the manual performance of music reading, this aspect of the process is readily measurable. Many views of the nature of the meaningful content of music have been expressed but the contention that *form* is essential and fundamental has been very persistent. Pratt has said, "It is worthy of note that in a subject like aesthetics, where opinion far outruns fact, there is to be found at least one principle upon which all writers agree, no matter whether their temperament inclines them in the direction of the far-flung speculations of Plato or the minute experimental researches of Fechner. The importance of form in general may be variously estimated. Never is it treated, however, as completely irrelevant, and its most striking and frequent mode of appearance is unfailingly seen to be by way of unity in variety, harmony, coherence, proportion, symmetry, the subtler balance of asymmetrical distributions, consonance, organic continuity, concordant relation of parts, homogeneity—the terminology is not always the same, but the underlying principle remains largely unaltered" (29, p. 79).

Pratt says, also, that "To the extent, therefore, to which form plays a role in the aesthetic experience it can be demonstrated that that portion of the experience (plus all the sensuous content) depends largely upon what the artist has done with his materials rather than upon the imaginative and associative supplementation of the person who beholds his work. The value of the experience has its permanent residence in the work of art itself, and although the experiential correlate of this work is subject to no little variation, its stability and likelihood of recurrence are far, far greater than can possibly be the case with those experiences richly filled out with associated and extraneous meanings and imaginings" (29, pp. 89-90). This formal character of music makes it generally different from our verbal language. The printed symbols of a musical composition represent a complex melodic, rhythmic, harmonic and dynamic organization which is embodied in the manual execution of the composition. The executed tones of music *constitute* the melodic, rhythmic, harmonic and dynamic form symbolized by the printed score. The spoken word, in oral reading, is as much a symbol as the printed word and is not an embodiment of the thing, process, or relation symbolized (excepting, of course, the exclamation, emotional cry, and modernistic nonsensical verse).

It seems evident, as Pratt has said, that "There is nothing in the wide world that a musical phrase can not mean when supplemented by associative bonds contributed by the listener or suggested by the composer or critic." . . . "For those, however, who cling jealously to the loveliness of sheer tonal quality, the charm of the suggestions and meanings which hover close to the intrinsic character of music's formal structure lies chiefly in this, that these meanings just beyond the world of sound seldom reveal corporeal concreteness. The suggestion of personal struggle and effort, let us say, which

music can so effectively convey, derives primarily from the close similarity between skillfully manipulated accents, rhythms, tempi, pitch-differences, and movement (plus the effects of dynamism), and the actions and motions of those who in real life struggle and strive, so that the perception of one not infrequently evokes the state of mind which was responsible for the other" (29, pp. 239-240).

The expression and the appreciation of the emotional and non-tonal experience associated with a musical composition are achieved *by means of* the executed rhythmic, melodic, harmonic and dynamic forms. The primary meaning, then consists of these forms and the only objective evidence of comprehension is the execution of the forms. Perhaps, in general, musical compositions may be said to have a more direct and profound emotional connotation than verbal compositions but this is always secondary. Any "program" or train of associated ideas is likewise secondary. Musical comprehension is, in the first place, comprehension of the structure of the tonal pattern symbolized by the notation. Anything apprehended in addition to this must be either an interpretation or an associate of the pattern.

Briefly, direct measurement of the reader's comprehension of the primary meaning of a musical composition is experimentally feasible. Records of the performance of a composition will reveal the accuracy of the reader's effective comprehension.

EXPERIMENTAL ANALYSIS

In this investigation the experimental problem has been the determination of the number and durations of reading pauses, the sequential placement of pauses, and the eye-hand span for the reading of three types of musical material.

The three musical selections used are shown in Figures 1, 2, and 3. Selection No. 1 represents the harmonic type of organization. The eight measures from a hymn are made up of a succession of common chords having conventional harmonic relations and there are very few accidentals. Selection No. 2 represents the melodic type of organization. The eight measures from a minuet by Bach have only two voice parts and there are few accidentals, but, when read at a lively tempo, proved difficult enough to require attentive reading by the subjects. Selection No. 3 represents the single-melody-with-supporting-chords type of organization. The right and left hands are employed alternately in playing the melody while the accompanying chords are played largely by the right hand.

Records of the reading of 15 well trained musicians were made. Nine of the 15 subjects were professional musicians in the sense that they were being paid for teaching (privately or in public schools) or were employed as musicians in various kinds of public entertainment. The remaining six were active musicians who were members of orchestras or other musical organizations and appeared frequently in public performances. All the subjects had specialized in piano playing but nine of them played some other instrument or were skilled performers in solo or part singing. Seven persons in the group had studied two or more years in special schools or conservatories of music and two had studied with eminent European teachers. All of the individuals of the group were women.

Tests of visual acuity (without correction) showed that seven of the group had normal vision in both eyes. Subject F

had normal vision with the right eye but very poor vision with the left eye. Subject H had normal vision with the left eye but slightly subnormal vision with right eye. Five of the subjects (G, I, J, L and M) showed poor uncorrected vision for both eyes (8/20 to 12/20 by the Snellen method of indicating relative acuity). These measurements of acuity were secured because the subjects were required to read without their corrections. All of the subjects with subnormal vision in both eyes were myopic and were able to see music at the piano well enough to read normally without the aid of correcting lenses.

The Dodge method of making photographic records of eye movements was used. This method has been described by Dodge (9, 10). The camera was mounted over a grand piano. The music rack of the piano was replaced by a large frame covered with cardboard which screened the camera and its accessories from the subject. The lens and its supporting tube projected through the cardboard screen and the music to be read was held in a wire frame just below the lens. The music was well illuminated (25 foot candles) but the lamp shade was adjusted so that the intensity of illumination on the screen decreased rapidly beyond the music.

An automatic carbon arc light was used as the source of illumination for the eye. A blue filter between the light source and the eye greatly reduced the brightness and distractibility of this light but transmitted practically all the light that is photographically effective on orthochromatic film. The angular relation of the light source to the eye was such that light from this source did not fall on or near the fovea during the reading. Also, the light received by the camera was reflected from the central region of the cornea.

Between the arc light and the reader's eye a circular disc was rotated at the rate of 5 revolutions per second by means of a synchronous motor. Nine of ten equal segments of this disc had perforations which admitted the light to the eye in discrete flashes at the rate of 50 per second. Leaving one of the ten segments unperforated provided time units of 5ths of a second as well as 50ths of a second on the records.

A lens of long focal length (12 in.) was used at a distance which gave a magnification of five times. This made it possible to place the selection to be read just below the lens and have it at the same time at a normal reading distance from the subject's eyes.

The recording of both vertical and horizontal movements or components of movements was accomplished by placing in front of the lens of the camera the simple doubling device used in the Hardy ophthalmometer. (Similar devices have long been used in determining astronomical distances.) This beam-splitting device is made of two weak prisms which were placed in front of the lens of the camera so as to refract half of the light passing through the lens in one direction and the other half in the opposite direction. One of the two images secured in this way was focused upon a vertically moving film and the other was focused upon a horizontally moving film. On each film was recorded the directional component of a movement at right angles to the direction of movement of the film. By requiring the subject to fixate prescribed reference points, records were made by means of which it was possible to determine the two dimensional coordinates of each reading fixation.

At the focal plane of the camera, a gear-sprocket train run by an electric phonograph motor carried the film (35 mm.) at a speed of 5.2 cm. per second. The gear-sprocket train was made in one unit which could be removed from the camera and run by hand so that it could be used to carry the developed records when the locations of successive reading pauses were determined.

Perhaps the most serious limitation of this photographic method when applied to the study of eye movements in music reading is the necessity of maintaining an absolute fixation of the head. This requirement has been a source of difficulty in many studies of eye movements and, when movements of the fingers and arms of the reader are involved in the process of reading, the difficulty becomes a major technical problem. The device used to hold the head in place was attached to a wall behind the subject. Adjustable clamps about and above the head were held in a frame which could be moved up or down to suit the subject's habitual position at the keyboard. However, any number of clamps applied to the skin of the head will do no more than prevent relatively large movements. The teeth of the upper jaw provide the one place of attachment which may be used to secure a close approximation of immobility. They are commonly employed, in attempts to fixate the head, by using a thin but rigid biting-board against which the jaws of the subject are firmly set. Although a biting-board is an unfortunate distraction for music readers, it is effective in eliminating head movements *if the subject is successful in maintaining a strong contraction of the jaw muscles.* In order to provide optimum conditions for successful fixation of the head, the biting-board attachment to the head support was made so that it could be rotated about either of two axes at right angles to each other making it possible to fit the board into the natural arrangement of the teeth of each subject. Also, the board could be moved vertically and horizontally independently of the supporting frame. But, with all of these adjustments and patient care in using them, a distressingly large number of the records could not be used to determine the locations of fixations because of head movements.

In addition to the records of the movements of the eyes, records of the performance of the hands on the keyboard were made. Each key of the middle five octaves of the keyboard was made to serve as part of an electric switch. Depressing a key closed a circuit through a small flashlight bulb (focusing filament type) located in an adjoining room where a camera carrying a continuously moving film provided a photographic record of the light from the bulb. The wire forming the circuits through the flashlight bulbs was run into the body of the piano over the keys where one end of each circuit was inserted into a small cup of mercury mounted just above a key and the other end was held just above the cup of mercury by a small upright attachment on the key so that any depression of the key would carry the end of the wire into the mercury. These switches were silent in operation and had no perceptible effect on the action of the keys. Frequent cleaning of the contact points was necessary. The light bulbs connected with the keys were placed in a straight row and were separated by small black cardboard shields. Between groups of 12 bulbs (representing octaves at the keyboard), additional lights were inserted to provide six parallel time lines on the piano records. Intermittent flashes of light at the rate of 5 per second were

secured from the time lights by a contact attachment on the synchronous motor used to provide time for the eye movement records. The time lines served also as reference lines which greatly facilitated the reading of the piano records. The flashlight transformation of the keyboard performance was photographed by means of a panoramic camera—described by Miles & Shen (24). A special loading chamber was built onto the back of this camera so that long strips of film (78 mm. wide) could be moved continuously at a uniform rate by an electric phonograph motor.

In order to determine the relation between the eyes and the hands throughout the reading a special device was constructed which would start the time lines on all records simultaneously. A shutter placed between the arc light and the eye closed a switch in the circuit of the time lights for the piano record at the same time that it released light to the eye and so started the time line on the eye movement records. Since only 5ths of a second were recorded on the piano record and the latency of the time lights for the piano record was not balanced by an identical latency for the eye movement records it is apparent that absolute simultaneity was not achieved. However, the maximum deviation from simultaneity was negligible when considered in relation to the significant units involved in determining the relation between eye and hand, i.e., the durations of notes and reading pauses.

In making the records, the following procedure was used for each subject. After the test of visual acuity, the recording apparatus was shown to the subject and a general description of the method of photographing eye movements was given with special emphasis upon the importance of preventing head movements. Then the subject was asked to try playing at the piano with the head supported. At first, only the head clamps were used, but later, the biting-board was added. During 15 minutes of miscellaneous reading and playing, the subject became somewhat adapted to the unusual conditions and the head support was readjusted as often as seemed advisable in order to attain a maximum of security with a minimum of discomfort.

The camera was then focused on the right eye and a selection of music very similar to selection No. 1 was placed on the rack below the lens with a blank sheet of paper covering it. The subject was told that this selection was being presented as a preliminary sample of the kind of selection to be read immediately after it so that the approximate tempo at which the following selection should be read could be determined. The tempo was to be the maximum permissible for the kind of music presented or the fastest that could be managed without a large number of errors. The subject was told, also, that three red dots had been placed on each of the selections to be read; one on the left side of the page at the level of the lower half of the staff, another on the left at the level of the upper half of the staff, and a third on the right side of the page just above the treble staff. And these dots were to be directly fixated in the order indicated by the experimenter before beginning to read the music. (These dots were used to secure reference fixations on known points.) A ready signal was given, the music uncovered, and the experimenter said, "look at the lower dot on the left, now the upper one, now the right, and now play." These instructions were given slowly enough to allow the subject to make a sure fixation on each dot. As the subject read the selection, the experimenter

watched the movements of the points of light on the ground glass focusing plate. This provided a check on the adequacy of the fixation of the head. After a warning to the subject to keep the jaws firmly closed on the biting-board and to avoid winking if possible, selection No. 1 was placed in position for reading and uncovered as the camera motors were started.

Preliminary samples were presented before selections No. 2 and No. 3 and the same procedure used as for No. 1. The selections were presented to all subjects in the order in which they are numbered.

After making the records for each subject, the experimenter asked the subject whether any of the selections had been read before the records were made. Previous readings were reported by two subjects. The records for these two readings of familiar material were not included among the records from which the results reported below were secured.

TABLE 1
Reading data for the three selections
(Time unit is one second)

Subject	Total Reading Time	Ave. No. Notes per Pause	Ave. Pause Duration and S.D.		No. Errors
		Selection No. 1			
L	16.5	1.68	.29	.12	6
M	17.5	1.62	.30	.10	5
I	18.9	1.39	.27	.09	5
G	20.2	1.51	.33	.08	2
O	20.9	1.53	.35	.14	10
B	23.7	1.78	.44	.16	2
J	24.1	1.56	.41	.20	6
A	24.3	1.65	.42	.19	5
H	27.2	1.35	.40	.20	3
K	28.5	1.44	.44	.25	0
Ave.	22.2	1.55	.36	.15	4.4
		Selection No. 2			
K	14.8	2.00	.38	.18	5
I	15.0	1.57*	.31*	.12	14
M	15.5	1.57*	.31*	.11	6
F	15.9	1.64	.34	.14	0
G	17.5	1.40	.31	.14	1
A	19.1	1.64	.38	.19	11
N	21.2	1.32	.36	.16	0
D	22.9	1.45*	.42*	.19	2
O	23.1	1.45*	.42*	.22	19
J	24.6	1.45	.48	.26	11
Ave.	19.0	1.55	.37	.17	6.9
		Selection No. 3			
F	14.9	1.77	.37	.21	7
L	14.9	1.92	.39	.23	6
G	17.4	1.82	.45	.25	2
I	18.8	1.64	.42	.22	6
C	19.3	1.97	.52	.25	14
K	21.1	1.64	.49	.22	5
N	24.5	1.38	.48	.29	5
J	26.4	1.44	.53	.27	8
Ave.	19.7	1.70	.46	.24	6.6

* In these cases, two subjects have the same No. notes per pause and Ave. pause duration. In both cases, the difference in reading time is explained by the omission from the table of the third figures after the decimal points.

RESULTS

Number of Reading Pauses

The number of reading pauses required to read any kind of material is significant only when considered in relation to the amount of material read. For this reason, it is customary, in word reading, to determine the average number of pauses per line. In this study, the average number of notes per pause has been used although this average is inversely related to the number of pauses.

There is some danger that the average number of notes per pause will be considered as equivalent to the number of notes seen by the reader at each pause of the eyes. This may or may not be true. The necessity of comprehending the melodic and rhythmic relations of notes may cause considerable overlapping of perceptual fields in continuous reading. The average number of notes executed per reading pause is not necessarily equivalent to the number of notes clearly seen at each pause.

In Table 1, the subjects are arranged in order according to the amount of time

used in reading each selection. The table shows that the average number of notes per pause was the same (1.55) for selections No. 1 and No. 2. Selection No. 3 shows a somewhat larger average number of notes per pause (1.70) and, if both notes and accidentals are included, the average number of symbols per pause is approximately twice as large for this selection (3.02) as for Nos. 1 and 2.

TABLE 2
Average number of notes per pause for treble and bass parts of the three selections

Subject	Selection No. 1		Selection No. 2		Selection No. 3	
	Treble	Bass	Treble	Bass	Treble	Bass
A	1.43	1.91	1.92	1.37		
B	1.65	1.91				
C					2.12	1.60
D			1.60	1.24		
F			1.85	1.37	2.12	1.15
G	1.30	1.76	1.60	1.13	2.12	1.23
H	1.05	1.84				
I	1.38	1.39	1.71	1.37	1.90	1.15
J	1.48	1.64	1.66	1.18	1.71	.94
K	1.26	1.64	2.18	1.73	2.65	1.34
L	1.48	1.92			2.12	1.46
M	1.38	1.91	1.66	1.44		
N			1.50	1.08	1.52	1.07
O	1.34	1.76	1.66	1.18		
Ave.	1.37	1.77	1.73	1.31	2.03	1.24

Considering only the average number of notes per pause, the three selections were read with nearly equal efficiency. A considerable grouping effect is found for selection No. 3 where many accidentals were read with an increase instead of a decrease in the number of notes per pause. This increase is undoubtedly related to the vertical groups of three and four notes on the treble staff of No. 3. Similar groups do not occur in the other selections.

The average number of notes per pause has been determined for the treble and bass parts of each selection. The right and left hand parts of selection No. 1 are very similar in number and organization of notes. However, Table 2 shows that the average number of notes per pause is greater for the bass (1.77) than for the treble (1.37) part. It seems reasonable to assume that more pauses were used in reading the treble than in reading the bass because the dominant melody is in the treble part and errors in the reading of this part are more conspicuous than errors in reading the bass part. We may expect experienced readers, doing sight reading, to read the dominant melody more carefully than the accompanying parts.

In selection No. 2, the treble and bass parts are equally important, as far as melodic structure is concerned, but the number of notes on the streble staff is approximately double the number on the bass staff. Table 2 shows that the average number of notes per pause for the treble staff (1.73) is larger than but not twice as large as the average for the bass staff (1.31).

The treble staff of selection No. 3 contains a disposition of notes highly favorable to group reading. The arrangement of the notes on the bass staff is quite unfavorable to group reading. The average

number of notes per pause for the treble staff (2.03) is the largest average found for the different kinds of material and for the bass staff (1.24) it is, of course, the smallest obtained.

Duration of Reading Pauses

The durations of pauses were determined within a limit of error of .02 sec. The data of Table 1 show that the average pause duration for selection No. 1 (.36 sec.) is practically the same as the corresponding figure for selection No. 2 (.37 sec.). And selection No. 3, which was read with a larger number of notes per pause than No. 1 and No. 2, has a larger average pause duration (.45 sec.) than the other two selections. The difference between the average pause duration for selection No. 1 and No. 3 (.10 sec.) has a critical ratio of 3.8. Also, the coefficients of variation for the pause durations of selections No. 1, No. 2, and No. 3 are 42, 46, and 53 respectively indicating greater pause variability for selection No. 3 than was found for the other selections.

Table 3 gives the average pause durations for the treble and bass parts of the three selections. The difference between the average pause durations of the upper (.38 sec.) and lower (.35 sec.) parts of selection No. 1 is very small. Although more pauses were used in reading the treble than the bass part of No. 1, the average duration of the pauses was found to be closely similar for the two parts. However, for selection No. 2 and for No. 3, there is a considerable difference between the average durations for the treble and bass parts. (Differences in note arrangement for these parts have been noticed.) For selection No. 2, the difference between the treble (.44 sec.) and the bass (.28 sec.) is .16 sec. and the critical ratio is 5.3. For selection No. 3, the difference between the treble (.52 sec.) and the bass (.32 sec.) is .20 sec. and the critical ratio is 5.7. The longer pause durations on the treble than on the bass parts of No. 2 and No. 3 are accompanied by larger reading spans (notes per pause) on the treble than on the bass.

TABLE 3
Average pause durations for treble and bass parts of the three selections

Subject	Selection No. 1		Selection No. 2		Selection No. 3	
	Treble	Bass	Treble	Bass	Treble	Bass
A	.39	.44	.39	.35		
B	.43	.46				
C					.63	.27
D			.50	.35		
F			.39	.27	.39	.33
G	.32	.33	.37	.25	.56	.24
H	.39	.40				
I	.27	.27	.33	.28	.47	.28
J	.43	.38	.62	.31	.59	.43
K	.51	.35	.49	.23	.55	.33
L	.34	.23			.40	.37
M	.30	.31	.33	.27		
N			.44	.27	.56	.29
O	.38	.30	.56	.25		
Mean	.38	.35	.44	.28	.52	.32
S.D.	.07	.07	.09	.04	.08	.06

Tempo and Ocular Behavior

The subjects were allowed to choose a tempo according to the instructions given above and after trying a sample of very similar material. This choice was allowed for several reasons. First, an arbitrarily fixed tempo would probably be too fast for some and too slow for others of the subjects from the standpoint of obtaining records of their best possible performances. Second, comparisons of the rates of reading for different kinds of material can be made. Third, it makes possible a determination of the variation in reading time for the group of subjects. Fourth, it makes possible a determination of the relations between reading time and both the number of pauses and pause duration.

The subjects appeared to cooperate willingly and with genuine interest. In only three of the twenty-eight cases was the tempo selected slow enough to permit errorless reading. It is possible that in these three cases a tempo was selected which permitted more and longer pauses than were necessary for accurate reading. However, the knowledge that every aspect of the reading was being recorded constituted a strong motivating condition for the subjects.

In Table 1, we see that the average reading time for selection No. 1 (22.2 sec.) is longer than the average reading times for No. 2 (19.0 sec.) and No. 3 (19.7 sec.). However, the number of notes in selection No. 1 (89) is larger than for No. 2 (74) and No. 3 (69). The average *rate* of reading for selections No. 1 and No. 2 was 4 notes per second and average rate for No. 3 was 3.5 notes per second.

For an understanding of the manner of perceiving in music reading and the conditions which determine the rate of reading, it is important to know the relation between reading time and each of the two variables which constitute it, i.e., the number and the durations of reading pauses. Determinations of these relations are of doubtful value if subjects choose tempi which not only permit but also require more than the minimum necessary number and/or durations of pauses. But, for reasons stated above, it seems probable that the subjects of this experiment could not have read the selections at faster tempi without inordinate numbers of errors. Table 4 shows the results obtained in calculating the degree of correlation between reading time and both the number and the average durations of pauses.

TABLE 4
Correlation of reading time with number and average duration of pauses

Selection	No. 1	No. 2	No. 3
"r" for reading time and number of pauses	$.35 \pm .19$	$.58 \pm .14$	$.27 \pm .22$
"r" for reading time and average pause duration	$.89 \pm .05$	$.83 \pm .07$	$.82 \pm .08$

The small number of subjects used limits the significance of these coefficients but weight is added to the results by the fact that they are similar for all of the three selections. It is clear, for this group of subjects, that reading time is much more closely related to pause duration than to the number of pauses.

Frequency of Errors

An illustration of the records used in determining the number of errors is given in Figure 4. (See discussion of this

figure under Eye-Hand Span.) The errors shown in Table 1 are all omissions or substitutions. Some slight irregularities in rhythmic figures and in tempo were found but they were considered too small to be classified as errors. Where the omission of a note caused a break in the rhythm, only one error was counted.

The average number of errors for selection No. 1 (4.4) is smaller than the average numbers for No. 2 (6.9) and No. 3 (6.6). A special circumstance should be noticed in connection with the large number of errors for selection No. 2 made by subjects A, I, and J. These subjects read this selection in the key of E-flat instead of B-flat. This caused many substitutions of A-flat for A.

No systematic variation of errors with the other measurements is apparent. Subject O, in reading selections No. 1 and No. 2 and subject C, in reading selection No. 3 apparently selected tempi that were too fast to permit them to read with a desirable degree of accuracy. Subject O made nearly all of the errors in one or two measures of each selection. The errors of subject C were scattered throughout the eight measures.

Individual Differences

The range for the average number of notes per pause in reading selection No. 1 is .43 (1.35 to 1.78); for selection No. 2, it is .68 (1.32 to 2.00); and for selection No. 3, it is .59 (1.38 to 1.97). The lower limit is approximately the same for the three selections but the upper limit is distinctly higher for selections No. 2 and No. 3 than for No. 1.

The range for average pause duration in reading selection No. 1 is .17 sec. (.27 to .44 sec.); for selection No. 2 is .17 sec. (.31 to .48 sec.); and for No. 3, it is .16 sec. (.37 to .53 sec.). The range is approximately the same for the three selections but there is a progressive rise of the lower and upper limits from No. 1 through No. 3.

The range for variability of pause duration (in coefficients of variation) for selection No. 1 is 33 (23 to 56); for No. 2, it is 19 (36 to 55); and for No. 3, it is 15 (46 to 61). The range of variability for selection No. 1 is about twice as great as it is for the other two selections. It should be noticed, however, that the greater range of variability for No. 1 is caused entirely by the readings of that selection for which the pause variabilities were less than the pause variabilities for any of the readings of the other two selections.

The first column of figures in Table 1 shows that the range for reading time is very similar for the three selections. The range in *rate* of reading for selection No. 1 is 2.3 notes per second (3.1 to 5.4); for No. 2, it is 2 notes per second (3 to 5); and for No. 3, it is 2 notes per second (2.6 to 4.6).

An individual's position in any of the distributions of measurements for one selection may be quite different from his position in the distribution for another selection. Subject K is an extreme case. In reading selection No. 1, this subject used more than the average number of pauses of very long duration and obtained the longest reading time. In reading selection No. 2, subject K used a smaller number of pauses than any other subject; these pauses were about average in duration and the reading time was the smallest for this selection. For selection No. 3, K used a little more than the average number and duration of pauses and reading time. Subject I is a typical case. In reading selection No. 1, this subject used many more than the average number of pauses of very short duration and obtained a reading time below the average.

For No. 2, subject I used next to the smallest number of pauses of the shortest duration and the reading time was next to the shortest. And, for No. 3, the number of pauses was slightly more than average; the durations and reading time were a little less than average.

Subject L made few pauses of short duration, in reading selection No. 1; subject B made few pauses of long duration; subject I made many short pauses; and subject K made many long pauses. These are the various possibilities which are sometimes treated as "types" of reading. But the differences in the positions of subjects I and K in the three selections and similar cases shown in Table 1 indicate that music readers can not readily be classified according to types.

Differences in visual acuity, as measured by standard methods, were found among the subjects. However, no regular relation between visual acuity and the reading data has been found. Subjects with subnormal acuity (at 20 ft.) are found to be fast, slow, and average readers. One subject (K) who had normal acuity, obtained the longest reading time for selection No. 1 and the shortest reading time for selection No. 2.

Sequential Placement of Pauses

An examination of the plotted patterns of reading pauses has not revealed sharply different types of readers. Two forms of reading have been found but all subjects employ both forms. The subjects differ in the frequency with which they use the two forms and, for this reason, we may speak of tendencies to read in certain ways but hardly of types of readers. The illustrations of reading patterns in Figures 1, 2, and 3 were selected to show the greatest differences found among the subjects.

Figure 1 presents the sequence of reading pauses for subjects M, H, and L in reading selection No. 1. Subject M used, most frequently, a "vertical" form of reading (see the eight measures at top of Figure 1). In the "vertical" form, the subject's line of visual regard jumps from one half of the staff to the other and back again. This regular alternation of pauses upon the two halves of the staff and the high frequency of nearly vertical movements of the eyes characterize the "vertical" form of reading. Two pauses in succession on one half of the staff are found, for this subject, only in the sixth measure and between the seventh and eighth measures.

The pattern of pauses for subject H (middle eight measures of Figure 1) shows a frequent occurrence of two successive pauses on the treble half of the staff which give the pattern a "horizontal" aspect. (In many cases, two pauses appear on the upper part of one chord. Re-reading and regressions will be discussed below.) Horizontal movements on either half of the staff and the use of a minimum number of vertical movements characterize the pattern of pauses which is called a "horizontal" form of reading. (Stetson [34] has used the terms vertical and horizontal in a similar way in a discussion of music reading.) The clustering of pauses at the half cadence in the fourth measure should be noticed. Nine pauses are used here in a measure having only seven notes. This is apparently a case in which the conventional retarding of the tempo at a half cadence has allowed the reader to make more pauses than would be made in reading the same material without a reduced rate of execution.

The reading pattern for subject L (eight measures at bottom of Figure 1) shows both the "vertical" and "horizontal" forms of progression. But the read-

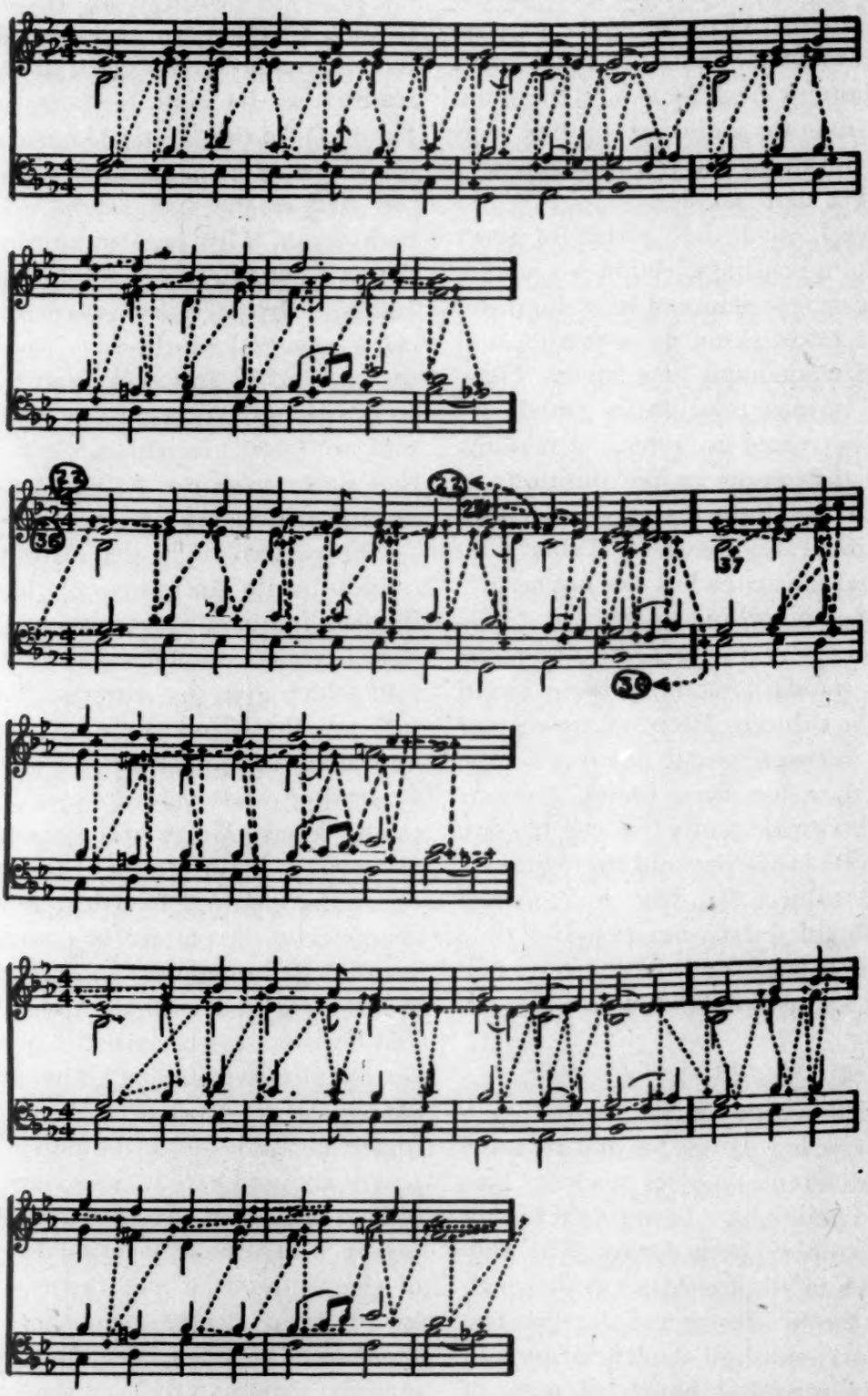

FIG. 1. Three patterns of reading pauses for selection No. 1 which represent the reading of subjects M (top), H (middle), and L (bottom). Successive points of regard are connected by broken lines.

ing of this subject is different from the reading of subjects M and H in another particular. At several places, subject L apparently read the parts of two or more chords as a unified segment of the composition. In the first measure, the first reading pause is on the treble part of the first chord, the second is a glance at the signature, the third is on the treble part of the second chord, the fourth is on the bass part of the second chord, and the fifth is on the bass part of the first chord. The parts of two chords were put together in an order which required a unified comprehension of them. Also, in the bass part of the second measure, only three pauses were used in reading the bass parts of four chords. The four chords were played without error. If we assume that inference was an important factor here, it seems probable that the inference was aided by some cues obtained during the reading of the bass staff. Measures 6, 7, and 8 show a similar kind of reading. In contrast to this, subjects M and H read the chords in succession from left to right making pauses on the two parts of each chord before going on to the next chord. Subject L made only 35 movements of the eyes from one half of the staff to the other. Subject M, who used the "vertical" form extensively, made 48 such movements.

In general, the "horizontal" form of progression was used more frequently in reading selection No. 1 than in the reading of the other two selections. Only three subjects (A, B, M) used the "vertical" form predominantly. Three subjects (H, I, O) used the "horizontal" form almost exclusively and four subjects (G, J, K, L) used it very frequently.

Illustrations of the reading of selection No. 2 are given in Figure 2. The eight measures at the top of this figure represent the reading of subject J. The general plan of this reading is "vertical." At three places, two successive pauses occur on the treble part, thus providing more pauses for the larger number of notes in this part.

Subject D (middle of Figure 2) used both the "horizontal" and the "vertical" forms. In the third measure, this subject read the treble part for the whole measure and then went back to read the bass part for that measure. This seems to be a very appropriate kind of reading for contrapuntal music. However, this kind of reading was done by only two of the ten subjects (D and I).

The sequential order of pauses for subject F (bottom of Figure 2) shows both the "vertical" and "horizontal" forms. And subject F made only 35 vertical movements while subject J made 42 such movements. Also, subject F read selection No. 2 in less than average time and made no errors while subject J used more time than any other subject and made 11 errors.

In general, selection No. 2 was read by means of a "vertical" sequence of pauses. Only three subjects (A, D, I) used the "horizontal" form as often as it appears in the middle eight measures of Figure 2.

In the second, fourth and sixth measures of selection No. 3 (Figure 3), two chords in succession occur on the treble staff without simultaneous notes on the bass staff. With bass notes on both sides of these chords, an approximately "horizontal" form of reading can hardly be avoided. The arrangement of the notes on the staff is a more important limiting factor in this selection than in selections No. 1 and No. 2. However, some differences in the organization of reading pauses are found among the subjects. All subjects show both the "vertical" and "horizontal" forms but the subjects who

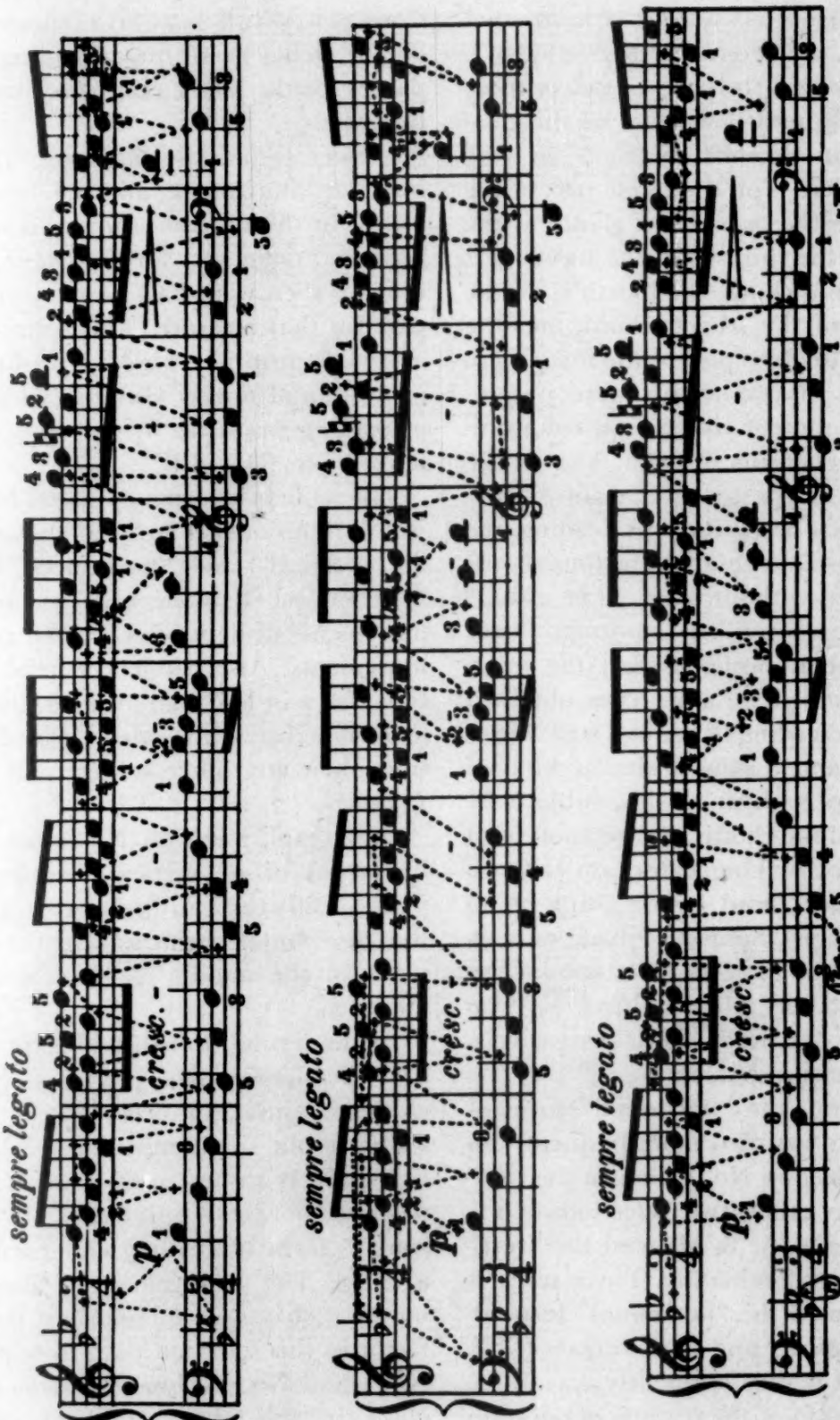

FIG. 2. Three patterns of reading pauses for selection No. 2 which represent the reading of subjects J (top), D (middle), and F (bottom).

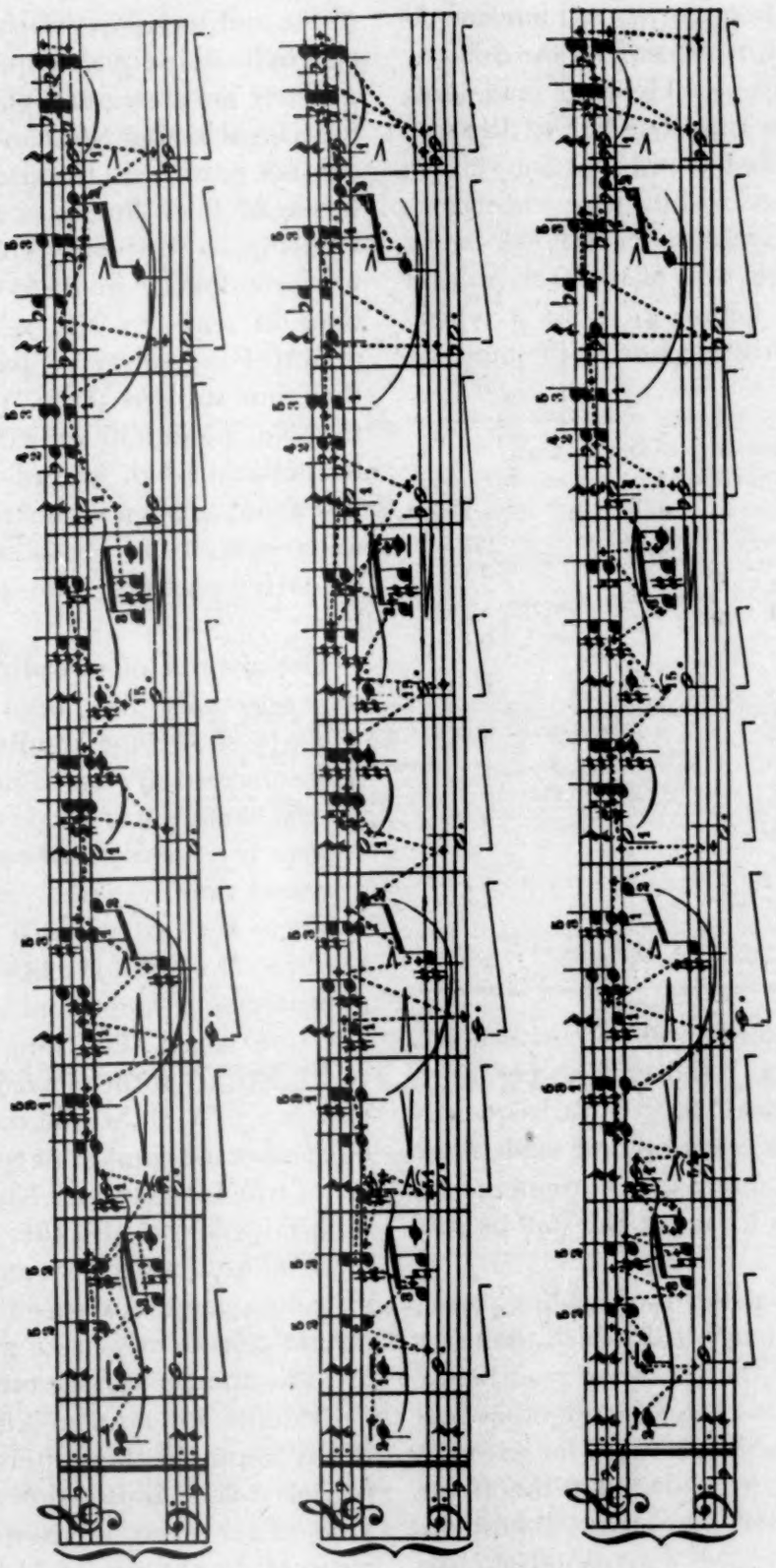

FIG. 3. Three patterns of reading pauses for selection No. 3 which represent the reading of subjects L (top), I (middle), and J (bottom).

use the "vertical" form most consistently show high frequencies of movements from one half of the staff to the other.

Subject L (top of Figure 3) made only 15 movements from one half of the staff to the other and shows superior skill in placing pauses within note clusters so that a maximum number of notes can be read at a single stop of the eyes. Subject I (middle of Figure 3) shows a typical pattern for this selection with some duplication of pauses and regressive movements. Subject J (bottom of Figure 3) used the "vertical" form most frequently in reading this selection and made more than twice as many (31) movements between the two halves of the staff as subject L.

TABLE 5
Number of rereading pauses

Subject	Selection No. 1	Selection No. 2	Selection No. 3
A	4	5	
B	4		
C			0
D		5	
F		3	1
G	11	7	1
H	15		
I	10	1	4
J	5	3	3
K	11	1	2
L	5		1
M	4	5	
N		4	6
O	9	5	
Ave.	7.8	3.9	2.2

The plotted patterns of reading pauses show the frequency with which the notes on one half of the staff were read before the simultaneous notes on the other half of the staff. The illustrations for selection No. 1 (Figure 1) show that the treble parts of chords were read almost invariably before the corresponding bass parts. This pronounced tendency was found in the reading of eight of the ten subjects who read this selection. The two exceptional subjects (B and I) read the treble and bass parts of chords first with approximately equal frequency.

There are ambiguous places in the patterns for selection No. 2 and No. 3, where it is not possible to be certain which part was read first. But it is clear that the tendency to read the treble part first is less pronounced in these two selections than in selection No. 1. Omitting the doubtful sequences of pauses, we find that four subjects (D, F, I, N) for selection No. 2 and four subjects (F, G, L, N) for selection No. 3 read the bass staff first about as often as the treble staff. The other subjects for both selections read the treble part first more often than the bass.

The amount of rereading for each of the selections has been determined. Table 5 shows the number of reading pauses located so close to previous pauses on the same notes or symbols that the subject is certainly reading the material a second time.

There is twice as much rereading for selection No. 1 as for selection No. 2 and approximately four times as much as for selection No. 3. The subjects who used the "vertical" form of reading for selection No. 1 (A, B, M) did only about half of the average amount of rereading. This is not true for selections No. 2 and No. 3. The table shows also that subjects who made more than the average number of rereading pauses for one of the selections do not consistently make more than the average number for the other selections.

Evidence for another kind of rereading is found in the patterns of reading pauses. A good illustration of this second kind of rereading is given in the eight measures at the top of Figure 3. In the first complete measure, three reading pauses were used in reading the three eighth notes in the bass part. In the fifth

complete measure, a similar group of three eighth notes was read correctly by means of one reading pause. The performance in the first measure is a kind of rereading in which there is a considerable overlapping of the areas of clear vision provided by the three reading pauses. The necessary extent of overlapping of successive visual areas may be an important factor in determining reading efficiency.

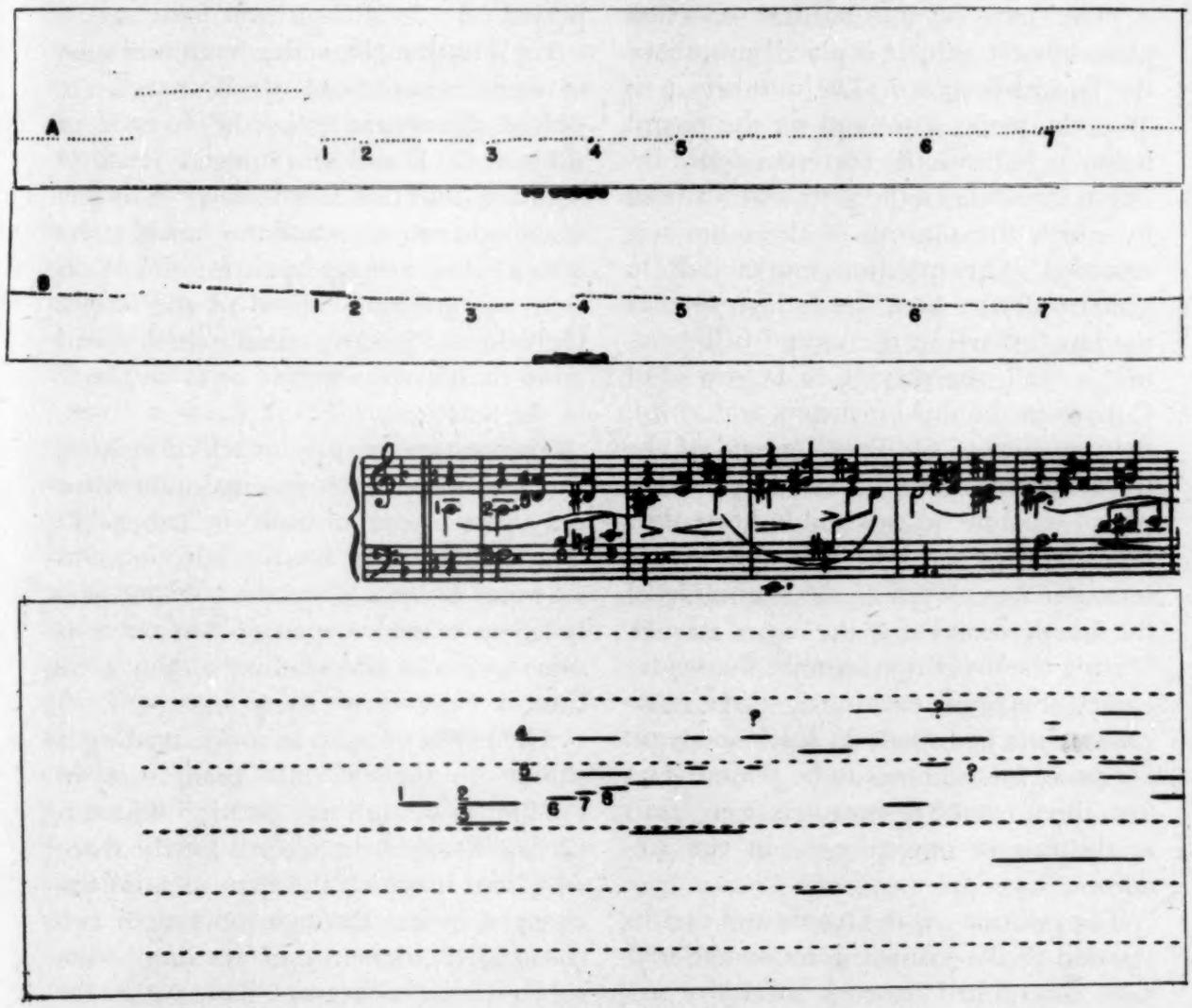

FIG. 4. Short samples of the records of the performances of the eyes (top) and the hands (bottom). (Explanation in text.)

Eye-Hand Span

Illustrations of the records by means of which the eye-hand span was determined are shown in Figure 4. Corresponding sections of the vertical and horizontal records of the pauses and movements of the eyes are shown at the top of the figure. The dotted line marked A is a record of the horizontal movements and positions of the eye and the line marked B is the simultaneous record of vertical movements and positions. The long movement from left to right at the beginning of the records is the movement from the second to the third of the reference points discussed above. Reading

pauses are indicated by the numbers 1 to 7. Numbers 3 and 6 mark pauses on the bass staff. The dots of these records indicate time in intervals of .02 sec.

The first part of a record of the performance of the reader's hands on the keyboard is shown at the bottom of figure 4. The part of the musical selection played by the subject is placed just above the keyboard record. The numbers 1 to 8 on the piano score and on the record below it indicate the correspondence between the notes on the score and the lines by which the playing of the notes was recorded. The question marks (left to right) indicate, first, the failure to play the last C-sharp in the second full measure; second, the playing of D instead of C-sharp in the third measure; and, third, the omission of the D at the end of the third measure. The broken lines of the record separate octaves and indicate time intervals of .2 sec. The first note of this selection was played at the beginning of the fourth second after the record started. During the first three seconds, the reader looked sharply at each of the three reference points and made at least one reading pause on the notes to be played. The first three complete measures were read at the rate of one measure in two seconds.

The positions of the hands and eyes in relation to the printed notes on the staff were determined for each successive second of reading. It then became possible to determine the number of the note or chord ahead of the hands at which the eyes were directed. This method made possible two or three determinations of the span for each measure of the three selections.

In reading selection No. 1, only two subjects (B and G) read as far ahead as the fourth chord beyond the hands. And a span as large as this was not maintained for more than one measure. The average span for this selection was 1.5 chords ahead of the hands. Subjects K and M never read farther than the second chord ahead of the hands and often they were still looking at the chord when it was played.

For selection No. 2, the maximum span of eight notes ahead of the hands appeared momentarily in the records of subjects G, J, and O. (Subjects J and O read this selection more slowly than any of the other subjects and they made many errors.) The average span for this selection was 3.1 notes ahead of the hands. Only one subject (N) failed to look ahead more than 4 notes at one or more places in the selection.

The maximum span for selection No. 3 was five notes and it was maintained for only part of one measure by subject L. The average span for the selection was 1.9 notes. Subject C was the only one who failed to exceed a span of two notes at some point in the reading of the selection.

The eye-hand span in music reading is similar to the eye-voice span in word reading in being very "elastic." There is no case in all of the records for the three selections in which the span remains unchanged in size through more than two consecutive measures of reading. Also, subjects vary in average size of span for the different selections. Subject A showed a low average span in reading selection No. 1 (1.0) and a high average span in reading selection No. 2 (3.8). Subject I showed a low average span for selection No. 1 (1.0), an average span close to the group average for selection No. 2 (3.3), and a high average span for selection No. 3 (2.5). Subject K obtained very low average spans for selections No. 1 (.8) and No.

2 (1.7) and an average span near the group average for selection No. 3 (1.7).

Discussion of Results

A comparison of the results obtained in studies of word reading with the results secured in this study of music reading shows that one musical note is practically equivalent to one word. The average number of words per reading pause reported in studies of word reading (8, 32) is closely similar to the average number of notes per pause for the selections used in this study. A chord of music corresponds to a phrase of words.

Published discussions of music reading often contain a comparison of the spelling of a word with the spelling of a chord. The letters of a word are likened to the notes of a chord. This is only an analogy, of course, and it has a certain value in emphasizing the importance of group reading. But the analogy is somewhat misleading. Letters and notes are not similar units from the standpoint of visual perceiving in reading. A better analogy would be a comparison of word spelling with note spelling, i.e., locating a note on the staff by means of the letter names of the lines and spaces. Reading each note of a chord separately is analogous to reading a phrase of words by making a pause for each word.

Average pause durations have been found to be longer in music reading than in word reading. Tinker (36) has reported pause durations for the reading of algebraic formulae that are similar in length to the pauses of music reading. The compactness of a notation seems to be related directly to the durations of the pauses required to read it. Further evidence which supports this generalization is found in the results for the reading of the treble parts of selections No. 2 and No. 3. These parts are spatially more compact and represent greater complexity of note relations than the parallel bass parts. For both selections, the average number of notes per pause and the average pause duration was greater for the treble than for the bass parts. The results for selection No. 1, which show similar pause durations for similar note arrangements on the two parts of the staff, are consistent with the generalization that notational compactness and pause duration are directly related.

The difference in the average number of notes per pause for the treble and bass of selection No. 1 is almost as great as the corresponding difference for selection No. 2, but there is much more rereading for selection No. 1 than for the other selections (Table 5) and nearly all of the rereading occurs on the treble staff (Figure 1). The average number of notes per pause for the treble part of selection No. 1 is, in one sense, spuriously reduced by the many rereading pauses.

The speed of music reading, for the subjects of this experiment, is more closely related to the durations of reading pauses than to the number of pauses. This has not been found in studies of word reading. For the reading of words, Tinker and Frandsen (40) have reported higher correlations between the number of pauses and perception time than between pause duration and perception time. Perception time is defined as the sum of the pause durations and is not exactly equivalent to total reading time. However, perception time is approximately ninety-four per cent of the total reading time. For this reason, it is highly improbable that the correlation coefficients reported in this study would be changed substantially if the movement

time of the eyes were subtracted from the total reading time.

The close relation between tempo and pause duration suggests that efforts to increase speed of reading should be directed primarily toward a reduction of pause durations. To do this, we must understand the conditions which determine the durations of pauses. The influence of notational compactness has been discussed. A further analysis of the effects of different degrees of complexity of note relations is suggested by the results for the three different selections.

The lowest pause durations recorded in Table 3 are those for the bass parts of selections No. 2 and No. 3 (.28 and .32 sec.). The bass part of selection No. 2 consists of a relatively simple melody progressing by regular chord intervals or by simple scale intervals throughout the eight measures. The bass part of selection No. 3 consists of a single note in four of the eight measures and a single note followed by one or three melody notes in the other four measures. Slightly longer pauses are recorded for the treble and bass parts of selection No. 1 (.38 and .35 sec.). Each of the two parts of this selection is composed of two voice parts which progress, almost always, simultaneously in regular chord formation. Still longer pauses are recorded for the treble part of selection No. 2 (.44 sec.). The treble part of this selection contains a melody in eighth notes which progresses by constantly varying intervals and which is read with a parallel melody in quarter notes in the bass part. The longest pause durations are recorded for the treble part of selection No. 3 (.52 sec.). This part consists of two, three, and four note chords which sometimes contain single notes of a melody which progresses alternately in the treble and bass parts. It is obvious that the melodic, harmonic, and dynamic relations of the notes in these different parts increase in complexity with the increase in the durations of the pauses used in reading them.

The general implication of this analysis is that the most rapid readers are those who use the shortest pauses. And those who use the shortest pauses are the readers who grasp most quickly not only the familiar harmonic patterns of notes but also the significant melodic, dynamic, and rhythmic relations of the notes. Factors such as number of notes per pause, the disposition of the pauses, the eye-hand span, and the degree of manual skill, probably influence the rate of perceptual apprehension of note relations in important ways.

The study has shown that, apart from the close relation between reading time and pause duration, the individuals obtained different ranks for the several phases of reading and these different phases varied diversely in the reading of the different kinds of material.

The "vertical" and the "horizontal" forms of reading may not seem to be essentially different when the "horizontal" form is used with only two successive pauses on one part of the staff. In the "vertical" form, the subject reads from the treble to the bass part of one chord and then from the treble to the bass of the next chord. In the "horizontal" form, the subject reads from the bass to the treble part of one chord and then from the treble to the bass of the next chord. In both cases, the parts of one chord are read before the next chord is read and chords are read in order from left to right.

However, the "horizontal" form has two advantages which seem especially important in the reading of contrapuntal

music. The distance that the eyes move in going from one group of notes to the next on one half of the staff is almost always much shorter than the distance they must move in going from notes on one half of the staff to notes on the other half. The movements of the eyes in reading are always rapid jerks and short jerks require practically the same amount of time as long jerks. But the extent and direction of each jerk is determined by the peripheral impressions available before the eyes move and visual acuity decreases rapidly from the center of the visual field outward. Advantageous placement of pauses is facilitated by using the nearer and clearer rather than the farther and vaguer peripheral cues. Also, where the rhythmic and melodic sequences are different on the two halves of the staff, there is an advantage in comprehending the relations of at least two note groups of one part before attempting to grasp the different relations of the notes of the other part. Of course, the extent of horizontal reading is limited by the necessity of carrying all parts forward as a unified pattern of musical tones.

SUMMARY

1. This is an exploratory study of music reading. The aim has been to establish certain "landmarks" which may be used as guides for further experimental studies. The first part of the study considers relevant research and the special characteristics of musical notation and its execution. The second part presents the method and results of an analysis of ocular and manual behavior in the reading of three different musical selections.

2. The average perceptual span for musical symbols varies between three and five notes for different kinds of note arrangements. The eye moves by rapid jerks between successive pauses. And it is only during the pauses that these small segments of notes may be apprehended.

3. The reading of piano music requires an exceedingly complex perceptual process. Pitch, temporal, dynamic and harmonic relations of notes must be perceived as parts of rhythmic and melodic sequences organized as phrases having constant or varying tonalities. Numerous special signs indicate the phrasing and style of playing.

4. Rhythmic and tempo requirements of music reading make it significantly different from word reading.

5. Notes on the treble and bass parts of the great staff are usually so far apart that both vertical and horizontal movements of the eyes must be used in preparing two parallel lines of material for a unified performance. Also, the sequence of reading pauses may vary appropriately with variations in note arrangements.

6. Music teachers agree that a wide eye-hand span is necessary for successful sight reading but their estimates of a desirable span differ greatly.

7. It is possible to measure musical comprehension by determining the accuracy of execution of the rhythmic, melodic, harmonic and dynamic forms symbolized by the notation.

8. Photographic records of eye movements and keyboard performances of fifteen trained musicians were made during sight-reading of short musical selections at a grand piano. A modification of the Dodge method of photographing eye movements enabled us to secure simultaneous records of the vertical and horizontal components of eye movements. The eye-movement and keyboard records were synchronized to make possible determinations of the eye-hand span.

9. The three musical selections read by the subjects represented "harmonic," "melodic," and "accompanied-melody" types of tonal arrangements. No. 1 consisted of eight measures of a hymn. No. 2 consisted of eight measures of a two-part minuet by Bach. No. 3 was an eight measure excerpt from a composition which was composed of a single melody with supporting chords.

10. The average number of notes executed per reading pause varied between one and two. The group averages for the three selections differed only slightly. Averages for the treble and bass parts of the selections showed that the spacing and harmonic grouping of notes are important factors. Accidentals do not seem to require extra reading pauses.

11. The average durations of reading pauses varied between .27 sec. and .53 sec. Average pause durations for selections No. 1 (.36 sec.) and No. 2 (.37 sec.) were reliably shorter than the average duration for No. 3 (.46 sec.). Pause durations for the treble and bass parts of the selections varied with the complexity of note relations represented.

12. The correlation of reading time and pause duration was distinctly higher than the correlation of reading time and number of pauses.

13. Progress along the musical score is accomplished in two ways. A regular alternation of almost vertical movements of the eyes from one half of the staff to the other half and frequent horizontal movements on one half of the staff with relatively few movements between the two halves of the staff have been found. The "horizontal" form of progression was used most frequently in reading selection No. 1 and the "vertical" form in reading selection No. 2. The arrangement of the notes in selection No. 3 required horizontal movements at some places but some subjects showed a much higher frequency of vertical movements than other subjects in reading this selection.

14. The treble parts of chords were almost always read before the corresponding bass parts. Notes on the treble staff were usually read ahead of notes on the bass staff but, in reading selections No. 2 and No. 3, some of the subjects read the bass staff first about as often as the treble staff.

15. Rereading involved from seven per cent to twenty-three per cent of all pauses used in reading selection No. 1. Rereading pauses occurred twice as often for selection No. 1 as for selection No. 2 and approximately four times as often as for selection No. 3. Over-lapping of successive areas of clear vision constituted a kind of rereading often found.

16. The eye-hand span was highly variable and never exceeded a separation of eight successive notes or chords between the eye and hand. The average span for selection No. 1 was 1.5 chords; for selection No. 2, it was 3.1 notes; and for selection No. 3, it was 1.9 notes.

17. There seems to be no basis for distinguishing types of readers. Individuals performed differently in reading different selections and in handling the different aspects of one selection.

18. A word and a musical note on the staff are equivalent units from the standpoint of the average number read per pause.

19. Average pause durations are generally longer in music reading than in word reading. Determination of the relative influence of various musical factors upon pause duration awaits further experimental study.

20. The "horizontal" form of reading

enables the reader to use the most distinct peripheral cues. This makes possible advantageous placement of reading pauses.

BIBLIOGRAPHY

1. Bean, K. L. An experimental approach to the reading of music. *Psychol. Monogr.*, 1938, *50*, No. 226. Pp. 80.
2. Brandt, H. F. A bidimensional eye-movement camera. *Amer. J. Psychol.*, 1937, *49*, 666-669.
3. Buswell, G. T. An experimental study of the eye-voice span in reading. *Suppl. Educ. Monogr.*, 1920, No. 17.
4. Buswell, G. T., & Lenore, J. Diagnostic studies in arithmetic. Chicago: Univ. Chicago Press, 1926. Pp. 212.
5. Butsch, R. L. C. Eye movements and the eye-hand span in typewriting. *J. Educ. Psychol.*, 1932, *23*, 104-121.
6. Clark, B. A camera for simultaneous record of horizontal and vertical movements of both eyes. *Amer. J. Psychol.*, 1934, *46*, 325-326.
7. Congdon, C. H. An innovation in the method of teaching children to read music. *Sch. Mus. Mon.*, 1904, *5*, 22-23, No. 22.
8. Dearborn, W. F. The psychology of reading. New York: Science Press, 1906. Pp. 134.
9. Dodge, R., & Cline, T. S. The angle velocity of eye movements. *Psychol. Rev.*, 1901, *8*, 145-157.
10. Dodge, R. An experimental study of visual fixation. *Psychol. Monogr.*, 1907, *8*, No. 35. Pp. 95.
11. Fairbanks, G. The relation between eye movements and voice in the oral reading of good and poor silent readers. *Psychol. Monogr.*, 1937, *48*, 78-107.
12. Fisher, H. Psychology for music teachers. London: Curwen, 1905. Pp. 181.
13. Freeman, F. N. The psychology of the common branches. Boston: Houghton Mifflin, 1916. Pp. 275.
14. French, E. A. The pedagogy of music reading. *Sch. Mus.*, 1919, *20*, No. 93, 7-11; No. 94, 11-21; No. 96, 26-42.
15. Gilford, N. Steps in sight-reading. *Mus. Teacher*, 1930, *9*, 503-504, 595, 655.
16. Gray, C. T. Types of reading ability as exhibited through tests and laboratory experiments. *Suppl. Educ. Monogr.*, 1917, *1*, No. 5. Pp. 196.
17. Jacobsen, O. I. An analysis of eye movements in reading music. Unpublished thesis, Univ. Chicago, 1926.
18. Jacobsen, O. I. Reading of instrumental music as shown by photographing eye-movements during the reading process. *Sch. Mus.*, 1931, *31*, No. 154, 10-11.
19. Jasper, H. H., & Walker, R. Y. The Iowa eye movement camera. *Science*, 1931, *74*, 291-294.
20. Judd, C. H., McAllister, C. N., & Steele, W. M. General introduction to a series of studies of eye movements by means of kinetoscopic photographs. *Psychol. Monogr.* 1905, *7*, No. 29, 1-16.
21. Kemp, S. Ten rules for becoming a good sight reader. *Mus. Observer*, 1926, *25*, 10-28.
22. Lee, E. M. Sight reading. *Mus. Teacher*, 1932, *11*, 430, 505-506, 617; 1933, *12*, 83.
23. Maier, G. First steps in sight reading. *Étude*, 1915, *33*, 868.
24. Miles, W. R., & Shen, E. Photographic recording of eye movements in the reading of Chinese in vertical and horizontal axes: Method and preliminary results. *J. Exp. Psychol.*, 1925, *8*, 344-362.
25. Morris, T. The right approach to sight-reading. *Sch. Mus.*, 1934, *34*, No. 169, 10-11.
26. Myers, S. S. First steps in sight reading. *Sch. Mus.*, 1914, *15*, No. 70, 30-36.
27. Ortmann, O. Elements of chord-reading in music notations. *J. Exp. Educ.*, 1934, *3*, 50-57.
28. Ortmann, O. Span of vision in note reading. *Yearb. Mus. Educ. Nat. Conf.*, 1937, pp. 88-93.
29. Pratt, C. C. Meaning of music. New York: McGraw-Hill, 1931. Pp. 253.
30. Quantz, J. O. Problems in the psychology of reading. *Psychol. Monogr.* No. 5, 1897, Pp. 51.
31. Sanders, H. Eye-training for music-students. *Étude*, 1921, 39, 570.
32. Schmidt, W. A. An experimental study in the psychology of reading. *Suppl. Educ. Monogr.*, 1917, *1*, No. 2, Pp. 126.
33. Smith, M. How to read music. *Étude*, 1907, *25*, 432.
34. Stetson, R. H. The psychology of reading music. *Proc. of M.T.N.A.*, 1925, *20*, 80-86.
35. Tilson, L. M. Can music reading be taught in the same way or according to the same principles as language reading? *Sch. Mus.*, 1913, *14*, No. 67, 21-24.
36. Tinker, M. A. Eye movement duration, pause duration, and reading time. *Psychol. Rev.*, 1928, *35*, 385-397.

37. TINKER, M. A. Visual apprehension and perception in reading. *Psychol. Bull.*, 1929, *26*, 223-240.
38. TINKER, M. A. Apparatus for recording eye-movements. *Amer. J. Psychol.*, 1931, *43*, 115-118.
39. TINKER, M. A. The relation of speed to comprehension in reading. *Sch. & Soc.*, 1932, *36*, 158-160.
40. TINKER, M. A., & FRANDSEN, A. Evaluation of photographic measures of reading. *J. Educ. Psychol.*, 1934, *25*, 96-100.
41. WHITE, R. T. The teaching of sight reading. *Mus. Teacher*, Jan. 1922-Jan. 1923.

II. MEMORY SPAN AND VISUAL PAUSES IN READING RHYTHMS AND MELODIES

BANCROFT LIBRARY OF THE UNIVERSITY OF CALIFORNIA
BERKELEY

II. Memory Span and Visual Pauses in Reading Rhythms and Melodies

KELVIN VAN NUYS and H. E. WEAVER
Department of Psychology, Oberlin College

INTRODUCTION

The three major aspects of a musical composition, rhythm, melody and harmony, present different tasks to the musician. The reading of rhythmic relations requires the apprehension of the time values of notes and the fitting together of these values within the regularly recurring cycle of measure accentuation. Melody must be apprehended by identifying the successive positions of notes on the staff in relation to a designated tonality. Harmony requires the recognition of related patterns of notes or chords. Each of these tasks may engender different characteristics in the ocular and manual phases of the reading performance.

As part of a program for the experimental analysis of music reading, this study is concerned with the influence upon certain measurable aspects of ocular and manual behavior of the rhythmic and melodic factors in music. The differences between rhythm and melody in notational representation and in their requirements for perceptual synthesis imply variables within the reading process which depend, in different degrees, upon these two aspects of music. The variables selected for special examination in this study are the immediate memory span and the durations of the reading pauses of the eyes.

THE PROBLEM

An earlier study of music reading (7) has shown a variation of the durations of the pauses of the eyes with the degree of complexity of the relations of notes. Since there are several kinds of note relations involved in music reading, it is necessary to study them separately or vary them independently if we wish to know the relative significance of each kind of relation within the complex whole. Rhythmic relations and pitch relations are basic to all music and an attempt is made in this study to determine their relative difficulty and the way in which they influence the durations of reading pauses.

The immediate memory span has been used as the criterion of difficulty. The use of this criterion enables us to secure evidence concerning conditions which determine the extent of the eye-hand span. The size of this span depends upon the amount of material that can be visually explored, perceptually organized and retained until executed by the hands. Musicians have declared frequently that a wide span is a requisite of good sight reading. But the influence of rhythmic and melodic note relations upon the size of the span has been unknown. We have been interested in determining whether there is a difference between the span for reading rhythmic relations and the span for reading the pitch relations of notes.

It is necessary to recognize that the rhythmic and pitch relations of music cannot be separated completely. A rhythm must be executed at some pitch level and a measure organization or basic rhythmic cycle is an indispensable part of every musical melody. However,

rhythms can be written which require no reading of pitch intervals and melodies can be written which require no reading of different time values.

To provide a basis for an experimental study of combinations of rhythmic and melodic relations, it has seemed necessary to determine, first, whether these two kinds of relations differ in difficulty when each one is isolated by reducing the other to an unvarying minimum and whether reading them in isolated form differs appreciably from reading them together.

Stated briefly, our specific task is to secure measurements of the extent of the immediate memory span and of the durations of reading pauses of the eyes for the reading of isolated and combined rhythmic and melodic (pitch) relations of notes.

THE READING MATERIAL

Three kinds of reading material were used: (1) selections in which only the time values of notes varied, (2) selections composed of different pitch intervals but having notes of only one time value, and (3) selections made by combining some of the rhythmic and melodic patterns of the first and second kinds of selections.

There were twelve notes in each of eleven different phrases. Three of the phrases were rhythms, six of them were melodies, and two were combinations. All of the phrases were written in the key of C; all were written on the same kind and size of staff paper; and none of the phrases contained accidentals or expression marks. Ten of the eleven phrases were written in 3/4 measure and the distance between measure bars was 2 cm. One of the melodies was written in 6/8 measure and the measure bars were separated by a distance of 4 cm. A reduced reproduction of the phrases is given in Figure 1.

The phrases were not graded or scaled in any precise way before they were used. This experiment is, in part, an attempt to provide a basis for determining the relative difficulty of different kinds of note arrangements commonly found in music. For this reason, some of the factors in music have been kept constant in the phrases employed and other factors have been varied in definite ways.

The three rhythmic phrases differed in the number of time values represented by the notes and in the arrangement of the rhythmic units. Rhythm A is composed of a relatively simple pattern which contains only three note values and the pattern of the first measure is repeated twice. Rhythm B contains four note values and a modified repetition of rhythmic units. Rhythm C has notes which represent six different time values and there is no repetition of units in this phrase.

The six melodic phrases differ in size of interval and grouping of notes. Melody 1 has a marked grouping of notes and a scalewise order of progression. Melody 2 is very similar to Melody 1 but the grouping of the notes is not accentuated by the use of cross bars. Melody 3 contains similar groups of notes in successive measures and the intervals are all relatively small. Melody 4 is composed of small intervals in irregular arrangement. Melody 5 has similar note groups in the first two and last two measures and many large pitch intervals. Melody 6 contains an irregular progression of intervals which vary in size from small to very large.

Phrases A_2 and C_4 were constructed by combining Rhythm A with Melody 2 and Rhythm C with Melody 4.

Four phrases similar to Melodies 2, 3,

and 5 and Rhythm A were used as examples. These examples prepared the subject for the reading of the phrases shown in Figure 1 which were read immediately after the examples.

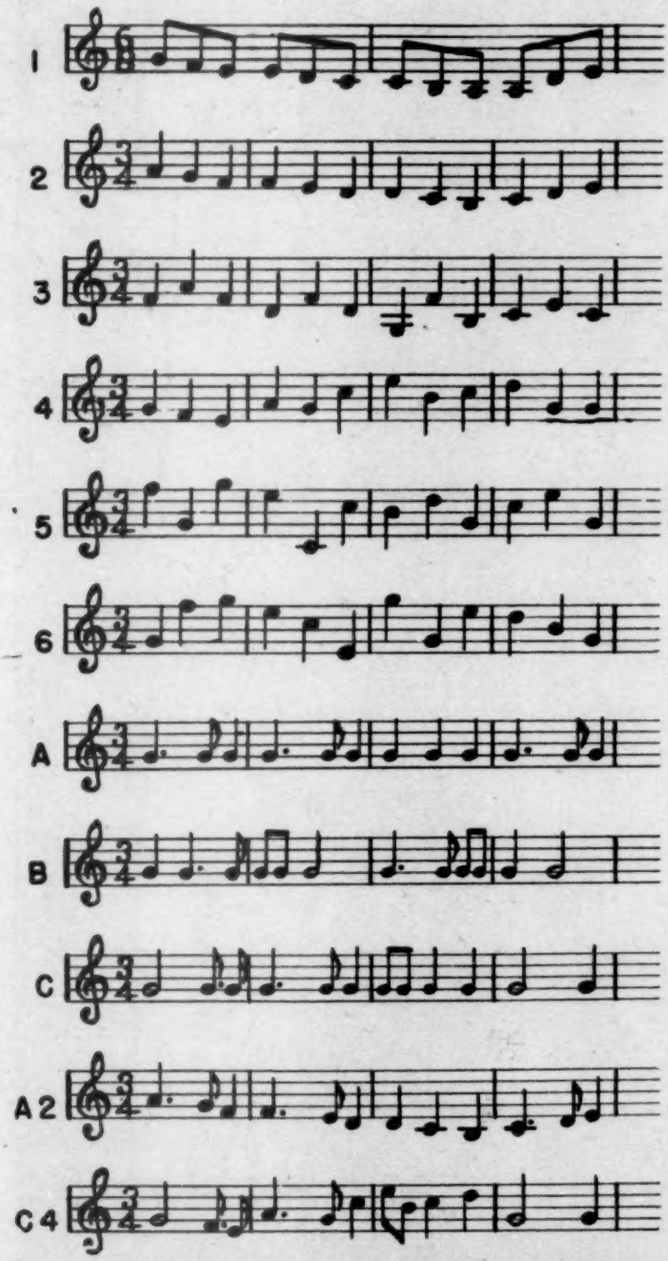

FIG. 1. A reduced reproduction of the musical phrases used in determining the immediate memory span.

APPARATUS AND PROCEDURE

The several phrases just described were read and played at the piano, and photographic records of the activities of the eyes and hands were made. The apparatus employed in making these records will be described briefly and then the details of the procedure followed in presenting the musical phrases and making the records will be discussed.

The Dodge method of making photographic records of the pauses and movements of the eyes was used (5). Light from a point source was reflected from

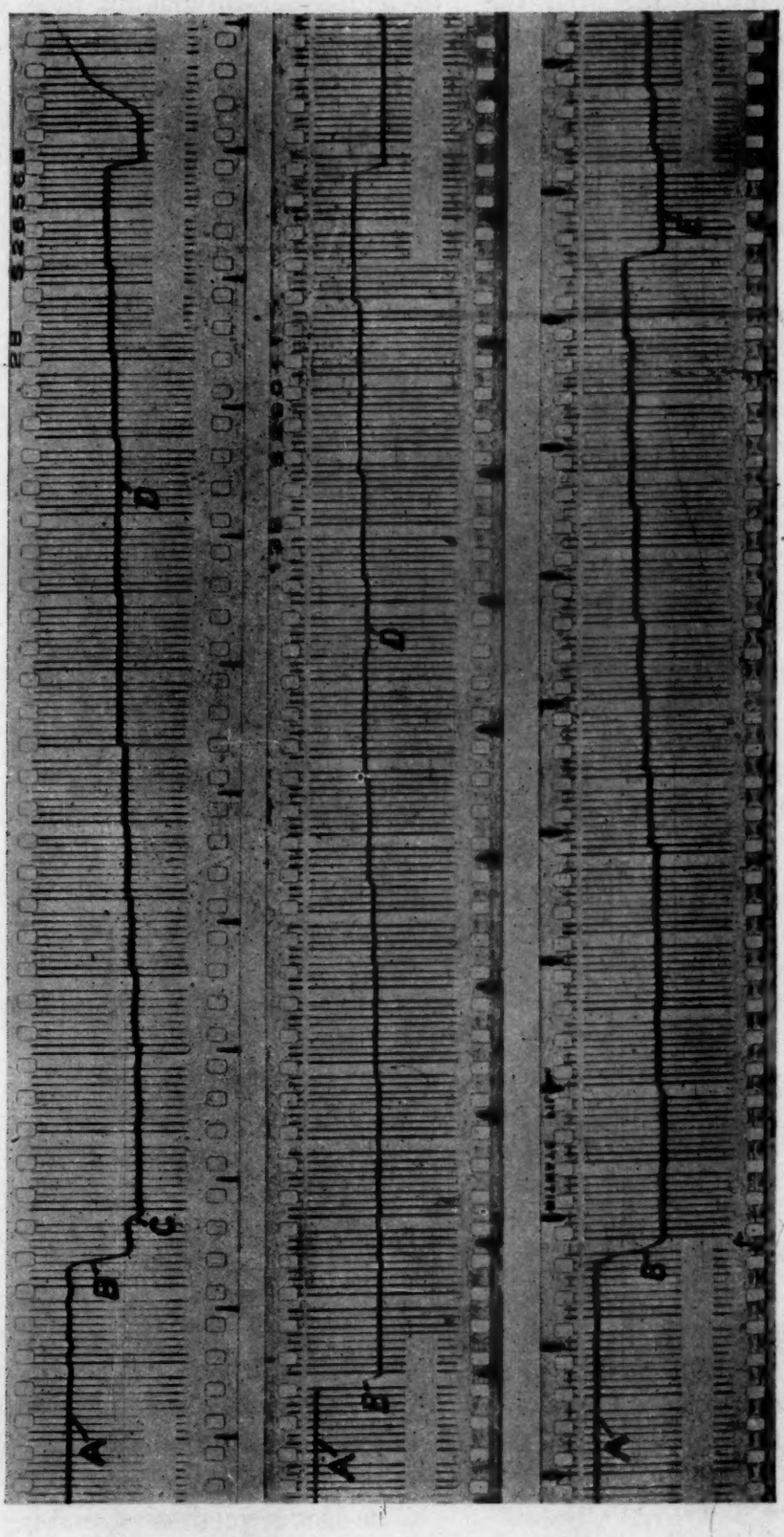

FIG. 2. Records of movements and pauses of the eyes. The letter A marks the pause of the eye while reader looks at second of two reference points on shutter of exposure device. B—leftward movement of eye toward beginning of musical phrase. C—a corrective movement used in finding beginning of phrase. D—a regressive pause of the eye. E—a regressive pause called a "repetition" in this study. Cross lines indicate time intervals of .02 sec.

the cornea of the reader's eye to the lens of a magnifying camera. While a subject was reading, this light was focused on 35 mm. film which was run continuously by a synchronous motor at the rate of 5.6 cm. per second.

A feature of the particular modification of the Dodge technique used in this experiment which should be noticed is the device used to record time intervals. A mercury vapor arc lamp, a synchronous timer, and a narrow slit placed adjacent to the film were used to make time lines across the film at right angles to the direction of movement and at the rate of fifty per second. The timer was constructed to mark nine successive intervals of .02 sec. each and then one interval of .04 sec. This method of recording time is adequate for a determination of the durations of reading pauses of the eyes (if two films at right angles to each other are used, the durations of movements can be determined) and the subject is not disturbed by flickering of the light directed upon the eye. Illustrations of the records of the pauses and movements of the eyes are given in Figure 2.

By using a lens having a focal length of 12 inches, we were able to keep all parts of the camera at a normal reading distance from the subject's eyes.

It is necessary to immobilize the head of the subject while photographic records of ocular behavior are made. This was accomplished by making for each subject a dental wax cast of the upper teeth on a thin metal plate. The metal plate was held rigidly in place by an adjustable frame which was built out from the wall behind the subject. The frame did not interfere with the movements of the hands and arms and did not obstruct the visual field.

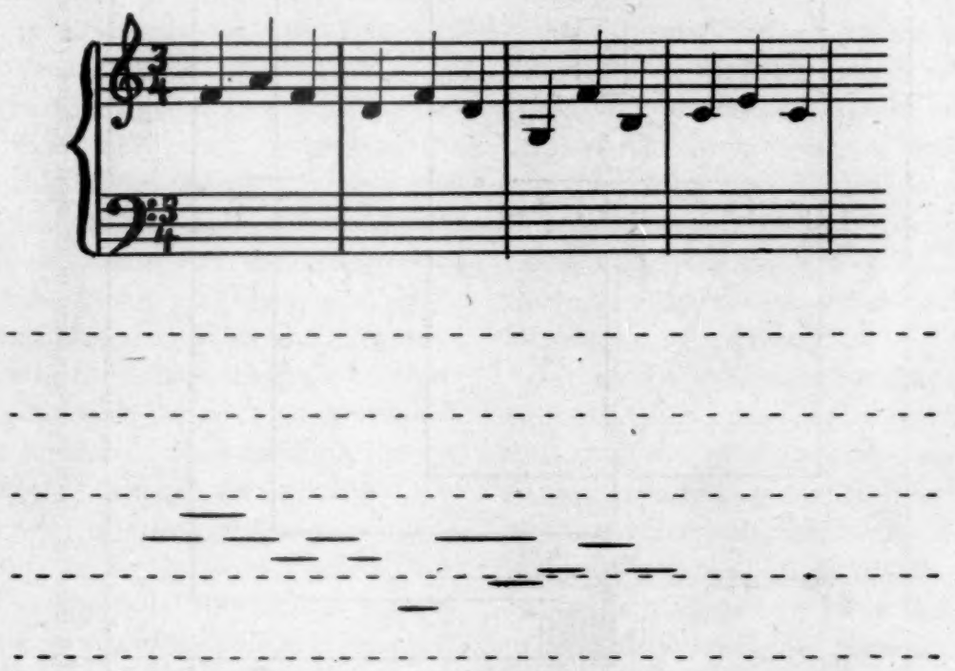

FIG. 3. Record of keyboard performance with recorded musical phrase above it. Broken lines mark octaves and time intervals of one-fifth second.

The execution of the musical phrases on the keyboard was recorded by a method previously described by Weaver (7). Each key of several octaves was made to serve as part of an electric switch. Depressing a key closed a circuit through

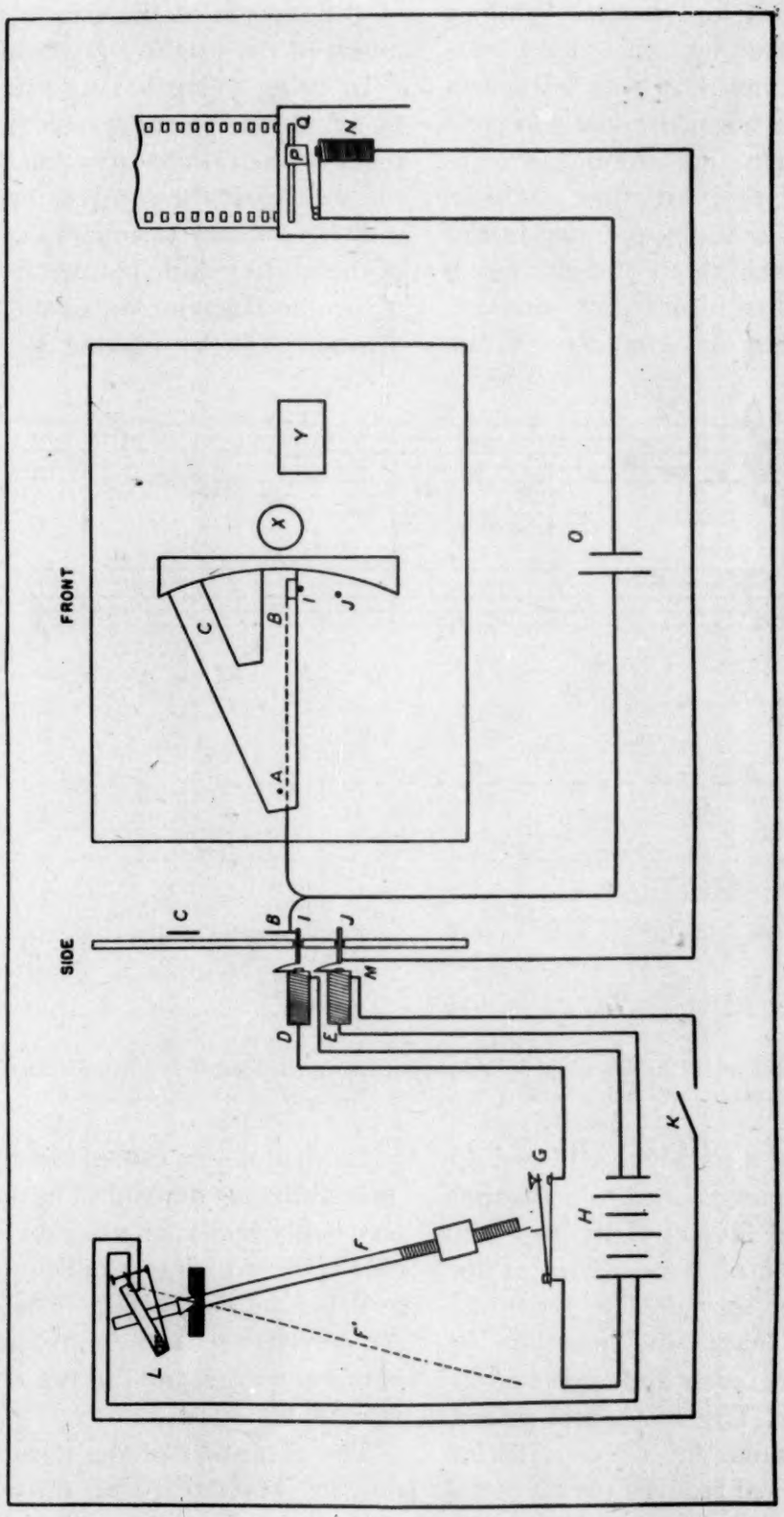

FIG. 4. Diagram of apparatus used to control presentation of musical phrases. (Description in text.)

a small flashlight bulb located in an adjoining dark room. The light bulbs connected with the keys were placed in a straight row and at the end of each group of twelve lights (one octave) a light was inserted to provide a time line and to facilitate the reading of the records. Intermittent flashes of light at the rate of five per second were secured from the time lights by a contact attachment on a synchronous motor. A camera carrying a continuously moving film made a photographic record of the keyboard performance. An example of the keyboard records is given in Figure 3.

The mechanism used to control the time during which the phrases were visible to the subjects and to record that time on the records of the activities of the eyes is shown in Figure 4. A large screen was placed in front of the camera. The lens of the camera extended a short distance through the circular opening *X* and the light used to illuminate the eye was projected through the opening *Y*. On the left side of the lens (from subject's viewpoint) a double shutter (*ABC*) was pivoted at point *A*. This shutter was operated by means of two electric magnets, *D* and *E*, and a timing pendulum *F*. When the switch *G* was closed, the pendulum was released and the circuit *GHD* was completed. The magnet *D* then pulled the small rod *I* from under fork *B* allowing it to drop down to rod *J*. When the pendulum completed its first full period, the switch *K* was closed. The pendulum continued to swing over to position *F'* at which point the mercury switch *L* was closed and the circuit through magnet *E* was completed. Rod *J* was pulled away from fork *B* and the shutter dropped a second time until fork *C* was stopped by rod *I*.

The musical phrases were placed behind fork *B* when it was in its first position as shown in Figure 4. The phrases were visible to the subject through the opening between the two forks only while fork *B* rested on rod *J*. The rod *J* was part of a circuit *JMNO* through the magnet *N*. This magnet and the little flag *P* which it operated were placed inside the camera near the slit *Q*. Since the magnet was activated only when the shutter rested on rod *J*, unbroken time lines indicate when a musical phrase was visible. (See Figure 2.)

An exposure time of 2.8 sec. was used for each of the phrases. Preliminary trials with different exposure times indicated that an exposure of about 3 sec. was just long enough to permit some musicians to read all of the simplest phrases and was not too short to permit them to read a substantial part of the more complex phrases.

We used a minimum reading time for two reasons. First, we wanted to be sure that the number and durations of pauses were not spuriously increased by allowing the subjects more than the necessary amount of time for reading. Second, we wished to force the subjects to extend the eye-hand span to its maximum under the pressure of a minimum time limit.

The subjects were requested to read and play as much as possible of each phrase but they were not allowed to start playing until they had read as much of each phrase as the exposure time would permit. This method of requiring the subjects to read for a limited period of time before starting to play has two advantages over a method which would allow the reader to read and play simultaneously. First, difficulties in keeping the head still while the activities of the eyes are photographed are reduced to a minimum. Second, the task of reading a whole phrase before starting to play is

a real challenge to the reader. The preliminary examples convince him that it is not easily done. And strong motivation is necessary to get some subjects to read more than a cautious distance of one or two notes ahead of the hands.

Before any of the phrases were read, each subject spent some time "trying out" the keyboard while in place before the camera and with the head supported. This allowed the subject to become somewhat accustomed to the unusual conditions of reading. Then the subject was told that, before reading each of the phrases, he should look sharply at each of two dots placed on fork *B* of the shutter. These dots were placed on the shutter in positions that corresponded to the beginning and end of each phrase. (The recorded distance between the pauses on these two known points was used in translating the distances between reading pauses on the records into the corresponding distances on the printed music.)

The following instructions were given to each subject before he tried to read any of the phrases. "The music consists of short phrases two or four measures in length. It is on the treble staff and is to be played with the right hand. When the shutter falls, you will see the music for only a short time. Read as far as you can but do not start to play until the shutter falls the second time. Then you will immediately play as much as you can of the phrase. You will not have enough time to memorize the phrase by reading all or part of it repeatedly. The phrases are short and you should not find it more difficult to play them immediately after reading them than to read as far ahead of your hands as possible in ordinary reading. This experiment will show how far you can read ahead of your hands. The first phrase you will read is a preliminary example. The phrase which you will read after it will have the same key signature, the same time signautre, and a very similar arrangement of notes."

When a subject had been seated as comfortably as possible at the piano with the head supported, the camera focused, and the instructions given, the following routine was used in presenting each phrase. 1. The subject's right hand was placed on the keyboard in position to play the first note of the phrase. 2. The subject was asked to look directly at the left dot on the shutter. 3. The cameras were started. 4. The subject was asked to look at the right dot. 5. Then a signal "go" was given, the shutter dropped, and the subject read the exposed phrase during a period of 2.8 seconds. 6. The eye-movement camera was stopped as the second drop of the shutter covered the phrase; the subject started to play what had just been read and was allowed to continue, without interruption, as far as he could go.

The phrases were presented in the following order: 2, 3, 4, 5, 6, A, B, C, 1, (interval) A2, C4. Previous experience had suggested that pauses for rhythms might be longer than pauses for the melodies. Therefore, the melodies were presented before the rhythms so that the procedure would not artificially increase any difference that was found. The one exception to this order, Melody 1, was placed after the rhythms because of its close similarity to Melody 2. The two phrases A2 and C4 were read by 10 of the subjects 30 or more days after the phrases A, C, 2, and 4 were read. No change in the procedure was made for the reading of these phrases.

During the month between the reading of the first and second group of phrases, a preliminary examination of

our records had shown that some of the subjects were making several regressive movements during the reading of the phrases. And, in reading some of the melodies, about half of the subjects had glanced back to the beginnings of phrases to make two or three pauses just before the exposure ended.

Because of uncertainty in regard to the effects of this rereading upon the durations of reading pauses, 5 additional phrases were prepared. After the subjects had read phrases A_2 and C_4, they were asked to read the 5 additional phrases, one change having been made in the procedure. Instead of playing the phrases only after the end of the exposure period, the subject was permitted to start playing during the exposure period and was allowed to continue *ad libitum*.

Two of the new phrases were very similar to melodies 3 and 5. They are identified in the tabulation of results as phrases 3′ and 5′ respectively. Two of the phrases were similar to Rhythms B and C and are identified as Rhythms B′ and C′. The fifth phrase was a combination of rhythm and melody and is identified as A′3′ for a similar reason. Each of these phrases was made one measure longer than the phrases shown in Figure 1.

THE SUBJECTS

The twelve men who acted as subjects in this experiment had met the requirements in academic and musical training for entrance as full time students in the Oberlin Conservatory of Music. We did not attempt to rate them either in amount or quality of musical training. The amount of training they had received at Oberlin varied from one to four years. They were all near the normal age for college students. We did not attempt to select those who were reputed to be either exceptionally good or poor sight readers. All but two or three of them were specializing in piano playing. The group may be characterized as consisting of above-average amateur musicians.

RESULTS

All of the results for the first eleven phrases used in this study represent a reading performance in which the reader is attempting to apprehend and organize four measures (12 notes) of relatively simple material ahead of manual execution. The relative difficulty of the phrases is shown by the numbers of notes correctly executed. Details of the reading process and differences in performance corresponding to differences in difficulty are shown by the number of notes of each phrase explored visually, the numbers of regressive and rereading pauses, the durations of reading pauses, and the number of notes correctly played per pause.

Notes Correctly Executed

Table 1 shows that all of the notes in five of the phrases (A, 1, 2, 3, and A_2) were played correctly by some of the subjects; one (A) by ten of the 12 subjects. Four of the phrases (4, 5, 6, and C_4) were so difficult that the average number of notes played correctly is less than half of the number of notes in the phrases. The more complex rhythms (B and C) were slightly more difficult than the simplest melodies (1, 2, and 3). The order of difficulty, from least to most difficult, is A, 3, A_2, 1, 2, B, C, 4, 5, 6, C_4.

Greatest difficulty was encountered by almost all of the subjects in the phrases having irregular progressions of pitch intervals. Even Melody 4, in which there was no interval larger than a fifth, was

more difficult than any of the rhythms. When the combination of Melody 4 and Rhythm C was read, the pitch intervals were executed as well as when Melody 4 was read alone. But the rhythmic values were read much less well in the combination than alone.

Notes Explored Visually

The locations of the reading pauses were plotted on copies of the phrases. When the position of each pause in relation to the notes had been plotted, it was possible to determine the amount of each phrase that had been explored by the reader during the exposure period. The number of notes explored includes all of the notes before and one note beyond the reading pause located farthest to the right on the phrase.

The two rows of figures at the top of Table 2 give the mean number of notes explored visually and the standard deviation for each phrase. These figures are presented for comparison with the figures of Table 1. The differences between the number of notes explored and the number played accurately show that, in reading phrases A, B, C, 2, 3, and A_2, the subjects were able to play correctly almost as many notes as they explored during the exposure period. In reading phrases 4, 5, 6, and C_4, the subjects usually explored approximately one measure more than they were able to play accurately.

It is important to notice that, even for phrases showing the greatest difference between the number of notes explored and the number played accurately, the subjects usually explored less than three full measures of material. In other words, they did not first explore all four measures of the phrase and find that they could not execute all the notes they had seen. This is interpreted as meaning that the subjects were doing the kind of reading that is necessary to achieve a genuine and effective extension of the eye-hand span to its maximum.

TABLE 1
Number of notes played correctly

Subject	Rhythms			Melodies						Rhythms and Mel.			
										A_2		C_4	
	A	B	C	1	2	3	4	5	6	A	2	C	4
Br	12	10	9		8	11	3	9	5	8	8	2	5
Be	12	7	6	12	7	7	5	4	3	12	12	1	4
Pe	12	3	9	12	12	12	7	4	6	9	12	5	5
Ro	12	4	8	10	11	12	9	4	3	9	6	7	7
Co	12	8		12	6	8	7	6	5	10	6	3	3
Bo	9		6	6	8	5	6	5	5	9	6	1	7
Pr	12	5	8	6	4	8	4	4	6	12	6	5	5
Wi	12	5	2	5	3	10	7	4	6	12	3	3	5
Po	12	7	4	7	3	11	5	6	4	12	3	0	9
Ga	12	9	6	7	9	8	5	5	2	9	9	3	6
Bs	12	11	8	6	12	11	4	9	5				
Mu	9	11	8	5	11	7	4	3	8				
Mean	11.5	7.3	6.7	8.0	7.8	9.2	5.5	5.3	4.8	10.2	7.1	3.0	5.6

Regressions and Rereading

Our maps of reading pauses show, also, that two kinds of leftward movements of the eyes occurred during the subject's attempts to organize and retain the material. The pauses listed in

Table 2 under the heading "Regressions" are pauses which were preceded by short backward movements of the eyes such as occur in word reading. The pauses listed under "Repetitions" were preceded by a long backward sweep of the eyes which occurred after the subject had reached the farthest point to the right attained in reading a phrase.

Regressions were used by about half of the subjects in reading each of the phrases. Rhythm B and Melody 1 are the only phrases for which as many as 8 and 10 of the subjects used regressions. For those subjects who used regressions, the average number employed varies between 1 and 2.

Repetitions signify uncertainty or the tenuous nature of the perceptual pattern prepared for execution. They were used more frequently in reading the melodies than in reading the other phrases. For the reading of the rhythms and the combinations of rhythm and melody, the total number of repetitions is small and the number of subjects who used them is small (2 to 4).

TABLE 2

Mean number of notes explored by the eyes, total number of regressions, and number of pauses used in exploring first parts of phrases a second time

	Rhythms			Melodies						Rhythms and Mel.	
	A	B	C	1	2	3	4	5	6	A_2	C_4
Mean No. Notes Explored & S.D.	11.6	8.7	8.2	10.7	9.9	10.3	8.7	8.7	8.3	10.8	8.1
	0.9	1.5	1.4	1.0	2.0	1.3	1.2	1.9	1.5	1.5	1.7
Regressions	9	10	9	22	14	9	9	6	5	8	8
No. Subjects	6	8	6	10	7	5	7	5	5	7	6
Repetitions	6	4	4	9	12	15	17	6	17	3	7
No. Subjects	4	3	2	3	5	6	8	4	8	2	3

Pause Durations

Reading pauses vary in duration with differences in complexity of note organization and pause duration is an important index of reading efficiency (7). An attempt has been made, in this study, to determine how certain specific conditions influence pause durations.

The average pause durations presented in Table 3 are the averages of all reading pauses which were completed within the exposure time. Pauses which were interrupted by a movement of the shutter either at the beginning or end of the period were not included. Also, we did not include the extremely short pauses made by some of the subjects in finding the beginning of a phrase. Any long sweep of the eyes to a new point of regard is usually accompanied by one or more corrective movements. The pauses between such movements are ordinarily very short and serve merely to orient the observer in relation to the point sought. In our records, these pauses were almost invariably followed by leftward movements and were clearly not pauses employed in reading the notes.

Table 3 shows that the simplest melodies required shorter average pause durations than the simplest rhythm. There is a difference of approximately 20 per cent between the pause durations of Melodies 1 and 3 and Rhythm A.

In general, pause durations show a tendency to be longer for rhythms than

TABLE 3
Average durations of reading pauses
(Time unit is one second)

Subject	Rhythms			Melodies						Rhythms and Mel.	
	A	B	C	1	2	3	4	5	6	A_2	C_4
Br	.31	.43	.34		.23	.24	.27	.25	.37	.38	.30
Be	.30	.41	.29	.32	.25	.28	.25	.27	.29	.29	.36
Pe	.34	.32	.38	.26	.32	.25	.22	.37	.36	.34	.39
Ro	.37	.25	.27	.19	.20	.23	.27	.24	.22	.24	.21
Co	.21	.28		.22	.29	.17	.26	.23	.25	.21	.23
Bo	.32		.27	.26	.25	.23	.21	.25	.28	.30	.28
Pr	.43	.41	.30	.30	.31	.26	.33	.32	.38	.41	.45
Wi	.25	.25	.33	.23	.23	.24	.23	.27	.27	.27	.23
Po	.33	.29	.39	.25	.27	.30	.30	.25	.27	.27	.30
Ga	.30	.32	.37	.30	.36	.28	.28	.45	.45	.35	.46
Bs	.33	.36	.37	.28	.36	.34	.35	.34	.29		
Mu	.26	.36	.43	.22	.31	.30	.35	.43	.36		
Mean	.31	.33	.34	.26	.28	.26	.28	.31	.32	.31	.32
S.D.	.05	.06	.05	.03	.05	.04	.05	.07	.06	.06	.09

for melodies. Durations were approximately equal only when the melodies were composed of irregular patterns of intervals which varied in size from very large to very small.

From the standpoint of reading efficiency, a difference in pause duration must be considered in relation to the number of notes read correctly per pause. If the average durations are directly proportional to the average number of notes correctly read per pause, the same reading time is required when long or short pauses are used in reading a specific selection.

Notes per Pause

Table 4 gives the average number of notes read correctly per pause for the different phrases. (The number of pauses for each phrase includes all pauses used in calculating the average pause duration plus all interrupted pauses having a duration of .15 sec. or more within the exposure period.) This table shows the same average number of notes per pause

TABLE 4
Average number of notes correctly played per visual pause

Subject	Rhythms			Melodies						Rhythms and Mel. A_2		C_4	
	A	B	C	1	2	3	4	5	6	A	2	C	4
Br	1.5	1.7	1.3		.7	1.0	.4	.9	.8	1.1	1.1	.2	.5
Be	1.3	1.0	.7	1.5	.6	.8	.5	.4	.3	1.3	1.3	.2	.6
Pe	1.5	.4	1.3	1.2	1.5	1.1	.6	.6	.9	1.1	1.5	.7	.7
Ro	1.7	.4	.8	.7	.8	1.0	.9	.4	.2	.9	.6	.5	.5
Co	.9	.8		1.0	.7	.5	.7	.5	.5	.8	.5	.3	.3
Bo	1.5		.7	.6	.7	.4	.5	.5	.5	1.0	.7	.1	.8
Pr	2.0	.7	.9	.7	.4	.8	.5	.5	.9	2.0	1.0	.8	.8
Wi	1.1	.4	.2	.4	.3	.9	.6	.4	.6	1.5	.4	.3	.5
Po	1.5	.8	.6	.7	.3	1.2	.5	.6	.4	1.5	.4	.0	1.1
Ga	1.3	1.1	.9	.8	1.3	.9	.5	.8	.3	1.3	1.3	.5	1.0
Bs	1.5	1.6	1.1	.7	1.7	1.4	.5	1.3	.5				
Mu	.9	1.6	1.3	.4	1.2	.8	.5	.5	1.1				
Mean	1.4	.9	.9	.8	.8	.9	.6	.6	.6	1.2	.9	.4	.7

for Rhythms B and C and Melody 3. The average pause durations are: .33 sec. (B), .34 sec. (C) and .26 sec. (3). These pause durations are directly comparable because they represent equal efficiency in reading. The critical ratio for the difference between Rhythm B and Melody 3 in average pause duration is 3.24 and, for the difference between Rhythm C and Melody 3, it is 4.21. These differences are statistically significant and they represent differences in reading time of 27 and 30 per cent respectively. The average number of notes per pause is much smaller for Melodies 4, 5, and 6 than it is for Rhythms A, B, and C. But the differences in pause duration between these melodies and rhythms are small.

When the same number of notes per pause is found for melodies and rhythms, the average pause duration is longer for the rhythms than it is for the melodies. And, when similar pause durations are found for melodies and rhythms, the number of notes per pause is greater for the rhythms than it is for the melodies.

Considering the results for the phrases which were combinations of the rhythms and melodies, we find that the simplest rhythm and ungrouped melody (A2) were read together with an average pause duration that was not longer than that required for the rhythm alone and with practically no decrease in the number of notes per pause. When the combination of Rhythm C and Melody 4 was read, the average pause duration was 6 per cent below that used in reading the rhythm alone and 14 per cent above that used in reading the melody alone. Also, the average number of correct notes per pause for the melody was slightly larger than it was for the melody alone but for the rhythm it was less than half of what it was for the rhythm alone.

The relatively small number of notes per pause for these simple phrases may be attributed to two conditions. First, in trying to organize a whole phrase in advance of its execution, the subjects probably used more "regressions" and "repetitions" than they would have used otherwise. Second, the subjects played correctly only about two-thirds of the notes that were explored by the eyes in reading phrases 4, 5, 6, and C4.

Effects of Removing Maximum Span Requirement

The conditions just described limit the interpretation of the results presented above to a consideration of maximum eye-hand span. By changing one requirement of the experimental procedure, it has been possible to secure results which permit a wider interpretation and application. This has seemed especially desirable in regard to the durations of reading pauses.

Table 5 gives the results for ten subjects who were permitted to play the notes both during and after the exposure period. The subjects could use any convenient eye-hand span. This is, of course, the way in which music is usually read. And this kind of reading, when compared with the kind of reading done in the first part of the experiment, shows a larger number of notes played correctly, a larger number of notes per pause, and fewer regressions for some of the phrases. However, the results for pause duration are similar for the two kinds of reading. Reading pause durations are longer for the rhythms than for the melodies and the difference is greater for the second than it is for the first kind of reading.

The increase in number of notes played correctly, when the subjects read without limitation of the eye-hand span,

was greater for the melodies than it was for the rhythms. If we use the number of notes accurately played as the criterion of difficulty in this case, we find that the two melodies were easier than the rhythms. And the melody with the large pitch intervals does not require a longer average pause duration than the simpler melody.

The results for phrase A′3′ are almost identical with the results for maximum span reading of Rhythm A alone. The expected results for Rhythm A′ alone have not been significantly changed by the removal of the maximum span requirement and the addition of the relatively simple pitch intervals of Melody 3′.

TABLE 5
Data for phrases read and played without the maximum span requirement

	Rhythms		Melodies		Rhythm and Mel.
	B′	C′	3′	5′	A′3′
Mean Duration	.36	.38	.29	.29	.31
S.D.	.08	.06	.04	.07	.05
Correct Notes	11.3	8.9	14.2	13.4	11.6
Notes per Pause	1.4	1.2	1.5	1.3	1.3
Regressions	5	10	5	2	9
No. Subjects	4	6	4	1	7

Discussion of Results

Two ways in which the memory span, as studied in this experiment, is different from the eye-hand span of unrestricted music reading should be noticed. First, in ordinary music reading it is necessary not only to retain the material included within the eye-hand span but also to prepare additional material at the same time. Second, we have used phrases which contained more notes than were included in the memory span of any subject. Although the amount of material before the musician, in ordinary reading, exceeds the immediate memory span almost all of the time, the subjects may have carried their visual exploration beyond any limit that would be reached in ordinary reading. Excessive extension of the span may have influenced the number of notes accurately played.

The reports of experimental studies of memory span contain some evidence concerning the effect of the amount of material presented upon the size of the span. Results reported by Gates (6) show a reduction in number of digits reproduced when series containing more than a certain optimum number are presented. Gates presented the digits by both a visual and an auditory method and he reports that "The average reduction amounts to 25.9 per cent with the visual method, and 36.6 per cent with the auditory method (6, p. 396)." This statement is qualified in the following way: "The figures show that the distractions offered by too long series either are not effective for all individuals or are not effective for some individuals at all times. On the average, however, 77.1 per cent of the individuals, when the visual method is used, and 84.5 per cent with the auditory method, fall below their span when the series exposed is longer than the span (6, p. 398)."

Caution is required in deriving any comprehensive generalization from the results reported by Gates. Binet and

Henri (2), in an earlier study, and Balser (1), in a more recent study, have reported figures which show that the memory span for words is greater for long than for short lists. (Of course, the items correctly reproduced represent a decreasing per cent of the number presented as list length increases.) Calhoon (4) has said that the memory span for disconnected words is not influenced by excessive list length. Although the averages reported for lists of 12 words are all larger than the averages for lists of 10 words, his figures show that the average spans for lists of 6, 8, 10, and 12 words are only slightly different from the average span for all lists. His treatment of the data may tend to minimize differences, but he believes that ". . . there is a span for reproduction of disconnected word lists which is independent of the number of words presented (4, p. 737)."

In a recent review of the literature on memory span, Blankenship (3) reports that span varies with the kind of material presented, the manner of presentation, the attitude of the subject, the amount of practice, and other conditions. This is further warning against attempts to use the results obtained in studies of other kinds of material as a basis for estimating the effects upon memory span of the amount of musical material presented.

Although memory span is influenced by many conditions, these studies do not lead us to expect that the visual exploration of several notes more than the number correctly executed has had more than a slight influence in determining the size of the span. The average number of notes explored but not accurately played was less than three for 8 of the 11 phrases. And, for the remaining 3 phrases, it was less than four. The differences in span found in this study are related to differences in note arrangement. All of the phrases used in studying span contained 12 notes and span varied with size of pitch intervals and uniformity of progression.

Although our method of determining the memory span differs from the usual method of presenting series which increase progressively in length until the subject's maximum is reached, we believe that our method approximates the conditions of normal reading more closely than the usual method. Our subjects sometimes explored more notes than could be retained, but it seems probable that this occurs in normal reading. And, whatever effect this has upon our results, the differences found represent differences in difficulty under conditions which closely resemble normal reading.

Rhythm A was distinctly easier than Rhythms B and C. The average span for Rhythm A was more than four notes longer than the average spans for Rhythms B and C. Melodies 1, 2, and 3 were similarly easier than Melodies 4, 5, and 6. If we compare the easy rhythm with the easy melodies and the more difficult rhythms with the more difficult melodies, we find the rhythms easier than the melodies in both cases. But the average pause duration is greater for rhythm than for melody. Longer pause durations for rhythms than for melodies were found, also, when the subjects were permitted to disregard span and to try merely to play all of the notes presented. And, for each of the combinations of rhythm and melody, the average pause duration was greater for the combination than for the melody alone. For the combination C_4, this average was not as large as it was for the rhythm alone and the rhythm was not nearly as well executed in the combination as it was alone.

The consistently longer pause duration for rhythm than for melody seems to indicate an essential difference between the two kinds of material in manner of reading. A comparison of the results for reading with and without the maximum span requirement suggests the nature of this difference.

For maximum span reading the melodies were more difficult than the rhythms. Release from the maximum span requirement enabled the subjects to increase the number of notes played correctly although the exposure time for the material was not changed. However, the increase was so much greater for the melodies than for the rhythms that the melodies became easier than the rhythms. When the reader had to organize and retain a sequence of pitch intervals, the reading of the melodies was relatively difficult. But when the reader was not required to do more than identify pitch level for one or a few notes ahead of execution, the reading of the melodies was relatively easy.

The reading of rhythm, when different time values are involved, always demands the organization of sequences of notes. All of the rhythmic beats of a measure, whether many or few, must fit precisely between successive measure accents. This fitting together of notes requires more time and a more comprehensive grasp of relations than is necessary in apprehending pitch level for one or a few notes. When the reader is not required to do maximum span reading he is not released from the task of organizing varied rhythmic beats within the stable limits of the fundamental rhythmic cycle.

The average pause durations for rhythms exceed those for melodies at different levels of complexity. Improvement in ability to apprehend rhythmic relations appears to be a primary requisite for an increase in rate of music reading. Similarly, a primary requisite for an increase in the memory span is improvement in the ability to apprehend melodic sequences. The per cent of visually explored notes executed correctly was smaller for melodies than for rhythms; the amount of rereading was greater for melodies than for rhythms; and the maximum span requirements constituted a greater restriction for the execution of melodies than for rhythms.

SUMMARY

1. The reading of musical rhythms and melodies has been studied by recording photographically the activities of the reader's eyes and the keyboard execution of musical phrases. One group of 12-note phrases, written on the treble staff, contained rhythmic patterns having no pitch changes, melodic patterns having notes of only one time value, and combinations of these rhythmic and melodic patterns. After the subjects had had preliminary experience in reading before the camera, each phrase was presented for a period of 2.8 seconds. During this time, the subject prepared himself to execute each phrase as completely as possible immediately after the presentation. Other similarly constructed phrases were presented for the same time but the subjects were permitted to start playing them during the time they were visible.

2. From the records of the keyboard performance, the number of notes correctly executed was determined for each phrase. From the records of ocular behavior, the durations of reading pauses, the number of notes visually explored, and the number of backward movements of the eyes were determined for each phrase. From both kinds of records, the

average number of notes correctly executed per reading pause was determined for each phrase.

3. The memory span for the group (average number of notes executed correctly after the presentation of a phrase) decreased as the complexity of note relations increased for both rhythm and melody. Considering the average memory span as an index of difficulty, the following order of difficulty was found. (a) The easiest phrase was a rhythm composed of a simple repeated figure involving only three different note values. (b) The next more difficult phrases were melodies progressing scalewise or by symmetrically arranged thirds. (c) More difficult than the simplest melodies were the rhythms having four or more note values in varied patterns. (d) The most difficult phrases were melodies having pitch intervals of a fifth or larger arranged in irregular progression.

4. The memory span for a combination of a simple rhythm and melody was only slightly smaller than the span for each alone. When a more complex combination of rhythm and melody was read, the span for the melody was equal to its span when read alone but the span for the rhythm was less than half as large as its span when read alone.

5. The difference between the number of notes explored visually during the exposure period and the number executed correctly is greater for the three most difficult melodies than it is for the rhythms. Also, the number of notes explored visually decreased as the difficulty of the phrases increased.

6. In the visual exploration of the phrases, backward movements of the eyes occurred more frequently for the melodies than for the rhythms.

7. Average durations of reading pauses of the eyes increased with the increase in complexity of note relations for both rhythms and melodies. A comparison of average pause durations for rhythm and melody yields the following generalizations: (a) When the average number of notes correctly executed per reading pause is equal for rhythm and melody, the average pause duration is greater for rhythm than for melody. (b) When the average pause duration is approximately equal for rhythm and melody, the average number of notes correctly executed per pause is greater for rhythm than for melody.

8. When combinations of rhythm and melody were read, the average pause durations exceeded the average durations for the melodies alone but they were not greater than the average durations for the rhythms alone.

9. When rhythmic and melodic phrases were read without the requirement of a maximum span between the eye and the hand, the average pause durations for the rhythms were approximately twenty-five per cent longer than the average pause durations for melodies.

10. The difference between the number of notes played correctly when maximum memory span was required and when it was not required was greater for the melodies than it was for the rhythms. This means that the reduction in the number of notes correctly executed caused by the necessity of apprehending a *related sequence* of notes in maximum span reading was greater for melody than for rhythm.

11. Melodic factors constitute the limiting conditions for memory span whenever the melody is not extremely simple. An increase in memory span depends largely upon improvement in ability to apprehend pitch patterns as stable

melodic segments of a composition.

12. Rhythmic factors constitute the limiting conditions for rate of reading or average pause duration whenever the rhythm is not extremely simple. And this implies that increase in rate of reading depends upon improvement in ability to grasp rhythmic figures.

BIBLIOGRAPHY

1. Balser, L. Experimentelle Untersuchungen über Gesichts- und Gehörseindrücke und deren Reproduktionen nach der Methode der Polyeidoskopie. *Arch. ges. Psychol.*, 1926, *54*, 1-22.
2. Binet, A. & Henri, V. La mémoire des mots. *L'Année Psychol.*, 1894, *1*, 1-23.
3. Blankenship, A. B. Memory span: A review of the literature. *Psychol. Bull.*, 1938, *35*, 1-25.
4. Calhoon, S. W. Influence of length of lists upon ability immediately to reproduce disconnected word-series auditorially presented. *J. Exp. Psychol.*, 1934, *17*, 723-738.
5. Dodge, R. An experimental study of visual fixation. *Psychol. Monogr.*, 1907, No. 35. Pp. 95.
6. Gates, A. I. The mnemonic span for visual and auditory digits. *J. Exp. Psychol.*, 1916, *1*, 393-403.
7. Weaver, H. E. I. A survey of visual processes in reading differently constructed musical selections. *Psychol. Monogr.*, 1943, *55*, No. 249.